

MILITARY SURGICAL MANUALS

NATIONAL RESEARCH COUNCIL

VOLUMES IN THIS SERIES

FOREWORD

THE Medical Department of the Army has been confronted with the necessity for enormous and rapid expansion paralleling that of the armed forces. The state of war has greatly increased the task of furnishing adequate medical care for Army personnel since battle casualties are added to the already wide range of diseases and injuries that must be treated.

Expansion of the medical establishment of the Army is entirely dependent on entry into the service of individuals from civil life. While most reserve officers have had a varying amount of military training, practically all medical officers will encounter problems in the military service entirely foreign to their previous experiences. These problems are by no means confined to those of an administrative nature; many are distinctly professional. The military situation imposes certain restricting factors which render impracticable some procedures that would be considered ideal in civil life. The goal of furnishing the best possible treatment to all individuals is the same in the Army as in civil life, but the means to attain that goal may differ materially.

There has been a marked tendency to specialization within the medical profession since the first World War. This tendency is fundamentally sound but does serve to increase the problems of many individual medical officers in time of war. Specialization cannot be followed to the same degree in the military service as in civil life. While many highly qualified specialists in the various fields of medicine and surgery will serve in like capacities in the Army, this cannot invariably be true. The great burden of medical care will fall on medical officers outside the highly specialized fields. It is thus essential that nearly all medical officers be familiar with the principles of military surgery. Recent advances in therapy have resulted in radical modification of certain principles of treatment that were formerly considered sound.

This series of texts presents in compact form essential up-to-date and reliable information regarding military surgery. The various sections have been written by outstanding authorities in their respective fields. They have been prepared for publication under the auspices of the Division of Medical Sciences of the National Research Council.

These texts will prove a highly valuable source of professional information for any surgeon desiring a knowledge of the principles of military surgery. Their application is not confined to military medicine, for most of the wounds and injuries of modern warfare may be duplicated in civil emergencies. The condensed form and avoidance of debatable points will render them very convenient for quick reference as well as for more mature study.

These volumes represent an important addition to the field of surgical texts. The individuals instrumental in their preparation have made a distinct contribution to civil and military medicine by their assemblage and presentation of this timely professional information.

JAMES C. MAGEE
Major General, U. S. Army
The Surgeon General

The naval medical officer is often faced with medical or surgical situations with which he must deal entirely alone and without the opportunity for consultation and assistance from other members of his profession. He may be the only medical man on a ship in the middle of an ocean, and any surgical emergency must be met by him and him alone. He cannot refer the case to a specialist; he himself must do everything that is necessary. It is important that he have the best assistance that professional books and journals can give him. A book such as this manual, which contains practical and essential things, readily accessible, is a real help to a medical officer and patient in this situation.

ROSS T. MCINTIRE
Rear Admiral, Medical Corps
Surgeon General, U. S. Navy

ORTHOPEDIC SUBJECTS

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INTRODUCTION

THIS volume is one of a series developed under the auspices of the Division of Medical Sciences of the National Research Council to furnish the medical departments of the United States Army and Navy with compact presentations of necessary information in the field of military surgery. The individual manuals are prepared under the auspices of the various subcommittees of the Committee on Surgery of the Division of Medical Sciences of the National Research Council and are edited by the Committee on Information.

The first four volumes cover the following subjects: plastic and maxillofacial surgery; ophthalmology and otolaryngology; abdominal and genito-urinary injuries; and orthopedic subjects. Succeeding volumes contain material on the following: burns, shock, wound healing, and vascular injuries; and neurosurgery and thoracic surgery.

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UNUNITED FRACTURES

Paul B. Magnuson, M.D.

CHAPTER I

FUNDAMENTAL PRINCIPLES AND ROENTGENOLOGIC EVIDENCE

IN a consideration of the causes and treatment of nonunion of fractures no generalized statement can be made which will hold true in even a majority of cases. The individual factors of each case, as always in medicine and surgery, must be carefully analyzed. The patient as a whole is as important as in any other diagnostic problem; his physical characteristics, his health, his temperament, all must be considered. No two human beings are alike, although each may be normal. Therefore, before the cause of nonunion in a particular case has been established, or before a method of treatment has been chosen, all factors must be studied. Unless this is done the percentage of cures will not be as high as it should be; things will be overlooked which should not be overlooked, and results will not be as satisfactory as would be the case were careful thought given to the cause, the preparation for treatment, and the treatment itself.

To evaluate the factors which contribute to nonunion the fundamental principles underlying the repair of fractures must be understood. This important groundwork can be briefly covered by quoting the report of the Fracture Committee of the American College of Surgeons, which represents the consensus of a large group of men particularly interested in the study and treatment of fractures. The headings have been added to the quotation, the end of which is indicated by three asterisks.

Pathology of Bones in Fractures

The local lesion in fracture cases is of paramount importance in establishing the general principles of treatment. When bone is broken there is coincident tearing of bone and soft parts—endosteum and periosteum—with vascular and lymphatic ruptures and thromboses. There may be laceration and contusion of muscle, fascia, and skin. There is death of bone, as well as of injured soft parts. The tissues are infiltrated by blood, lymph, and inflammatory exudate

HIGHLIGHTS IN TREATMENT OF UNUNITED FRACTURES

1. Secure the cooperation of the patient and have his mind in agreement with that of the surgeon that there is no short and easy route to union.
2. *Eliminate all systemic disease which would interfere with general health.*
3. Surround the injured bone with healthy tissue (skin and muscle) and remove all bone debris, fibrous tissue, and infected material.
4. Bring the patient's health to a maximal point before bone work is attempted; this includes nourishment, metabolism, circulation, muscle tone, and strength around the injured parts.
5. Secure adequate immobilization of fragments and institute physical therapy locally at the earliest possible time.
6. Avoid cross-strain and torsion in handling, after operation

The growing tissue is infiltrated with the calcium derived from autolyzed dead bone either in solution or in colloid state. The cells forming this tissue are derived from the soft parts of the bone—endosteum, marrow reticulum and periosteum—from the soft parts around the site of fracture, and from the lymphocytes infiltrating the part as a result of the inflammatory reaction. Within seventy-two to ninety-six hours this mass of cells, while loose meshed and friable, becomes an organized tissue uniting the ends of the bone and the adjacent soft parts. Unless there exists such mechanical obstruction as interposition of tissue, all fractures heal in this manner. This is the manner in which the healing process occurs for any wound wherever situated.

Deposit of Calcium

Calcium is then deposited in this newly formed living tissue, which then constitutes early callus formation. The deposition of calcium has been observed as early as seventy-two hours in sections removed from actual fractures. The calcium is apparently derived, for the greater part, from the calcium freed by autolysis of dead bone, and not from the blood calcium. The process then goes on to progressively denser concentration of deposited calcium until the callus becomes hard bone. With use and the action of normal stress and strain over a period of months this bone arranges its lines and channels to form the normal histological picture of bone. It frequently takes a year or more for the completion of this process.

In the meantime the organization of granulation tissue proceeds in the fibrin mesh throughout the affected soft parts and becomes organized tissue within a week. The effectiveness and rapidity of growth of tissue are dependent upon efficient circulation in the parts from which the cells are derived, and as stated above, is retarded and limited by excessive fluid exudate at the site of fracture.

Granulation Tissue

Healing by granulation tissue takes place in all fractures except where mechanical obstruction exists between the fragments. The slow deposition of calcium in the tissue produces so-called delayed union, whereas its absence produces so-called nonunion. Delayed and nonunion are more apt to occur in certain bones and certain portions of these bones even when all other factors are equal. Certain sites of fracture in some bones are therefore characterized by a prolonged "healing time" as the usual and expected result. Therefore, in addition to the other factors cited, the time needed for sufficient ossifica-

as well as transudate because of mechanical circulatory interference. This infiltration of the tissues causes the swelling and pain of the part, and is increased by handling of the extremity and movement of the fragments of bone. It is of significance that the blood, lymph, and inflammatory exudate rapidly clot, and that the two latter are even richer than blood in fibrinogen. Within forty-eight hours this extensive fibrin shows active organization by cell growth, and is replaced by organizing tissue.

Pathology of Soft Parts in Fractures

The tissue of the soft parts and the bone that have been killed by the trauma are autolyzed by ferments furnished by the death of the cells, and tissue fluids in the region of the fracture are permeated by a calcium compound derived from autolyzed bone. There are some who hold that the source of calcium is the blood stream. This process is slow and occupies several days. The swelling and infiltration reach their maximum in eight to twelve hours, and then circulatory disturbance from pressure and thrombosis adds an actual edema to the picture. The clotting of blood and exudate leaves a residue of their fluid contents which gradually diffuses toward the surface. This residue is important because the more fluid, whether exudate or transudate, present at the site of fracture the less efficient is the organization of the fibrin. In addition to this common picture there may be associated injuries of contiguous muscles, nerves, vessels, joints, tendons, and tendon sheaths, which must be considered as part of the lesion.

Process of Normal Bone Repair after Fracture

The actual mechanism whereby calcium is deposited in the tissues to form bone is unknown, as is the chemical form in which that calcium exists. But the rest of the process is sufficiently well established to give a definite idea of what happens: After the fracture lesion as previously described has appeared, the bone ends and the surrounding soft parts (soft parts of bone, and extraskeletal tissue which has undergone laceration and is present at the fracture site) are bound together by the interlacing mesh of the fibrin from clotted blood, lymph, and inflammatory exudate always present at the site of fracture. There is a certain amount of edema. Within a few hours fibroblasts appear in this fibrin clot as the beginning of the formation of granulation tissue. The more fluid element present, the less effective and rapid is the cell proliferation. Within forty-eight hours this organization has proceeded to a considerable degree.

and harden, thus increasing the visibility of fracture lines. If in the next weeks this process increases without the formation of external callus at any periphery a forecast of delayed union, fibrous union, or nonunion is justified.

Early evidence of infection in compound fractures cannot be seen in x-ray films. In a week or ten days softened areas may appear at or near the fragment ends which by comparison with previous films become convincing for infective osteitis. When such findings first appear after atrophy of disuse has become established, their detection becomes more difficult and uncertain. Actual bone loss must be recognized. In ascending bone infections the x-ray findings always lag behind the actual pathologic process. Similarly on healing the x-ray evidences of healing are not apparent until it is well established.

In subacute and chronic bone infections there may appear not only areas of bone destruction but also bone detritus, periosteal elevation and proliferation, sequestration, etc.

* * *

REFERENCE

1. Fracture Committee of the American College of Surgeons: The Principles and Outline of Fracture Treatment. Bull Am. Coll Surgeons. *15*: 3–32 (Mar.), 1931.

tion of the healing process to allow function depends on what the function of the part calls for in the way of solidity.

* * *

Fresh Fractures and Fractures after Surgical Treatment of Nonunion

The foregoing, of course, was meant to apply to fresh fractures. However, when a fresh fracture is reproduced by surgical interference, after nonunion has occurred, and the freshened ends of raw bone are brought together, the same process must take place in the healing as in a fresh fracture, except that in the former case the tissues are probably not so actively supplied with normal circulation, there is more fibrous tissue present, the muscles are more atrophied, and the patient's vitality has been somewhat depleted by long prior treatment and immobilization. Under such circumstances bone cannot be expected to form with the same facility as might be expected in the fresh fracture. Immobilization almost certainly will be necessary for a longer period, and frequently must be more stable and more carefully supervised.

Roentgenologic Evidence

Dr. Hollis E. Potter, in a personal communication, has given the following outine of roentgenologic evidence of nonunion. The quotation closes with the three asterisks, at the end of this chapter.

In simple fissures without displacement hardly visible at first discovery, the line of fracture may become quite visible in a week or two because of marginal demineralization normally present in first steps of callus formation.

In long bone fractures in children, new bone callus may be plainly visible before three weeks. Young adults may show callus by four or five weeks and occasionally older people may show definite bone callus thus early. In uncomplicated long bone fractures in adults there is frequently a delay beyond five weeks which does not in itself forecast a nonunion.

In impactions of spongy bone ends and in fractures of short bones without displacement, a decrease in fracture line visibility at four to six weeks without external callus formation argues strongly toward a proper union by internal callus only.

First evidence of nonunion may appear in four to six weeks where no callus is formed and the ends of fragments begin to smooth off

CHAPTER II

CAUSES AND PREOPERATIVE CARE

CAUSES

THERE has been much discussion about the cause of nonunion, but there has been no agreement and there can never be, because the cause in every case probably differs from that in every other case. Henderson wrote, "The etiologic factors are local and not systemic," and with this another surgeon can completely agree. Experience has shown that nonunion occurs most frequently in cases in which there has been improper reduction or ineffective immobilization, or in locations where there is lack of adequate circulation. These locations are the femoral neck, the intracapsular portion, the junction of the lower and middle thirds of the tibia, the carpal scaphoid, the lower third of the ulna, and the junction of the lower and middle thirds of the humerus. In many cases of fracture involving both bones of the forearm or of the leg one bone will heal and the other will remain ununited, or in multiple fractures all will heal with one exception, and the exception is usually located at a place which is difficult to immobilize or in which the circulation is notoriously deficient.

Some authors believe that glandular dysfunction has a bearing on lack of formation of bone, but this has not been proved definitely. However, the chemical processes and the metabolism of a debilitated patient cannot be expected to be normal. The general condition of the patient should be investigated before any major surgical procedure is attempted. Formation of bone, like formation of other tissue, whether it be nerve, muscle, or another part of the human body or its chemical mechanism, is influenced by the general state of health. Therefore, the patient should be restored to as complete health as is possible, before operation is performed. Certainly, in the light of recent experience, vitamin therapy; diet, well balanced and suited to the patient's needs; sunshine, and rest alternated with appropriate exercise should be prescribed. If nonunion already exists there can be no haste in instituting mechanical procedures, and a few months preceding operation devoted to restoration of health can

cle to move the joint through an arc that would be impossible if the muscle were forced to work against gravity. Light metal splints are used to support the site of fracture while the extremity is in the water. The Hubbard tank is used for exercise of the shoulder, hip and knee. The whirlpool bath is used for exercise of the elbow, forearm, wrist, hand, ankle and foot.

The sling suspension apparatus is another useful method of securing free, active exercise. The extremity is supported in one or more slings which are attached to ropes running through pulleys suspended from a Balkan frame. The patient, by holding the other end of the rope, eliminates the weight of the limb. Without the effect of gravity a weak muscle will be able to move the joint through a greater arc of motion.

Free active exercises are also given by instructing the patient to use movements designed to bring about normal action of a joint in a natural manner. For shoulder motion, he is instructed to use a hair brushing exercise; for elbow, to use a saw; for wrist, to use a hammer for driving small nails; for forearm, to turn a door knob or to use a screwdriver; and for fingers, crush a wet newspaper in water. In leg fractures foot exercises are important.

To overcome joint stiffness continuous gentle traction with a splint is useful and is aided by its removal four times daily for resistive exercises. Heat and massage should be used once daily. This treatment is useful in increasing circulation. Heat may be applied by using warm water in the Hubbard tank during underwater exercise, or with the whirlpool bath. Local radiant heat may be applied by an electric lamp baker.

Latent infection: In ununited compound fractures where there has been infection and the wound is healed, exercises, heat and massage should be used for the purposes set forth above, and also to determine the presence of a latent infection.

Scar tissue: Heat, massage and exercises should be used over scar tissue at the site of the ununited fracture, or at parts away from the fracture to loosen adhesions, stretch contractures and increase the circulation of the scar tissue.

* * *

Removal of Scar Tissue

In cases in which compound fractures have remained ununited, deficiency in the normal covering of epithelium and skin is often found. It is important to bring healthy, normal, pliable tissue into contact with the unhealed bone, and all scar tissue from the surface

make the difference between a successful and an unsuccessful surgical procedure.

PREOPERATIVE CARE

Once nonunion has occurred there can be no hope of securing union within a short time. Care and patience, with close observation and attention to details, will be necessary. Rough or thoughtless handling must not be tolerated. Procedures must be decided beforehand and careful preparation must be made whenever the fracture is to be handled.

Preparation of Fracture Location for Surgical Treatment

The mere fact that nonunion exists means that there is more hard, mature scar tissue in this location than is normal. There has been long immobilization. The tissues are atrophied and fibrosed. To joints which have been immobilized proper physical therapeutic measures should be applied. Force should not be used. Heat, massage, and active, as well as graduated gentle passive, motion should be used until maximal recovery has occurred. This will do much toward improving the health of the tissues controlling and immediately surrounding the fracture, by increasing pliability and restoring circulation. The patient should be encouraged to develop the muscles which control the injured part. This will require patience on the part of both surgeon and patient in many cases because the tissues have been dormant for so long a time.

Physical Therapy Preliminary to Operation

In a personal communication, Dr. John S. Coulter wrote the following paragraphs. The end of the quotation is indicated by three asterisks.

When it is decided that nonunion exists and surgery is necessary, it is often advisable, in preparation for surgery, to apply a light splint which will permit active exercise but will prevent deformity. Such exercise will improve muscle strength, increase circulation and joint function, and under these conditions an operation for bone repair may be performed with a better prospect of success.

The most important agent is exercise. It increases the circulation and is the only agent which increases muscle strength and helps overcome joint stiffness. Underwater exercise in a Hubbard tank or whirlpool bath offers a form of exercise which permits movement of a fractured extremity with a minimum amount of strain on the fracture, and because of the buoyancy of the water, enables a weak mus-

cle to move the joint through an arc that would be impossible if the muscle were forced to work against gravity. Light metal splints are used to support the site of fracture while the extremity is in the water. The Hubbard tank is used for exercise of the shoulder, hip and knee. The whirlpool bath is used for exercise of the elbow, forearm, wrist, hand, ankle and foot.

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and around the fracture should be removed prior to any surgical procedure. It may be necessary to cover the remaining defect with a large flap graft, and this may have to be done in several stages, but bone cannot be expected to heal if the circulation is cut off as a result of hard scar tissue surrounding the ends of the fragments. Removal of scar tissue has the additional benefit of eliminating possible walled-off foci of infection which might flare up and cause infection at the time operation was performed on the bone. This is especially true if nonunion occurred as the result of a previously infected wound. Good, healthy, normal skin should cover all areas before any attempt is made to fix the fragments. There should be no areas of abrasion or breakdown. It must be remembered that if nonunion is the result of prior infection, at least six months should elapse between the time of complete healing and any surgical work on the bone, such as bone graft or other form of internal fixation; the time element depends on the virulence of the preceding infection and on the ability the local tissues have demonstrated in combating it.

Treatment of Draining Wounds Due to Bone Infection

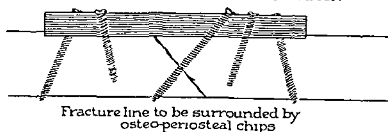
In some cases it is impossible to secure healing without removal of sequestra and infected fibrous tissue lying deep in the wound. In such instances it is sometimes permissible, or even advisable, to attempt to reduce and fix the fracture at the same time the sequestra and other debris are removed from the wound. This may be done if the infection is not too active, if it has existed for some time, and if there is no swelling and edema or signs of generalized infection. In doing this it may be necessary to shorten the bone, because no fixation apparatus should be inserted in the presence of infection; at least it should not be put into the bone lying within the wound. If shortening of the bone is necessary, a wide incision should be made, all scar tissue, sequestra and dead bone should be removed, and the ends of the fragments should be brought together at the expense of length of the bone. If either the lower leg or forearm is involved, both bones will have to be shortened. Obviously, the shortening should be made on the bone which is clean, as an entirely separate operation, so that infection will not spread from one bone to the other. It is in this type of case that the method advocated by Orr is most useful.

When all debris and low-grade tissue have been removed, and the ends of bone have been brought together firmly, they can be held, preferably by two pins placed far enough above and below the ends of the fragments to be away from the immediate vicinity of the draining wound.









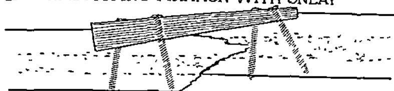


Fig. 1.—Some methods of internal fixation, including certain bone grafts.

Orr and Campbell both have advocated holding the fragments together snugly with vitallium steel plates and screws. Some surgeons never have felt that drilling holes through bone in an infected portion was advisable, although it has been done. The risk of spreading osteomyelitis is considered too great and the resourceful surgeon can find some other method to meet the requirements of the case in hand. The fewer foreign bodies of any kind introduced into an infected wound, the more kindly the tissues will react.

After the bone is fixed firmly and the fragments are held together, either by fitting in wedge formation (Fig. 1, B) or by some other method, such as putting the end of one fragment into the medullary cavity of the other, or cutting the ends of the fragments off square, the whole wound is packed with vaseline and gauze and is left completely open, fixed in a cast which will hold the tissues firmly even with massive dressings between the wound and the cast. If pins are used to hold the fragments together, pushing from above and below toward each other, they can be incorporated in the cast or held with a turnbuckle which is incorporated in the cast. The immobilization apparatus must be maintained in use for months. Rest for the wound, and rest and fixation for the bone, both of which are important for elimination of infection and healing of bone, are best provided by avoidance of manipulation.

Badgley reported forty-four cases in which treatment was by the method last mentioned; bony union was secured in eighteen, bony union with healed soft tissues in fifteen, bony union with persistent drainage in three, nonunion with healed soft tissues in three, nonunion with persistent drainage in four, and amputation for persistent nonunion and infection in one. However, he did not use any form of immobilization within the wound and he does not care to introduce foreign bodies or to drill bone in an already infected site. His method is good and conservative treatment.

The treatment known as the Orr treatment in this country was used extensively by Trueta in a large number of cases in the Spanish Civil War, and undoubtedly his results as a whole were better than with any other type of treatment of fractures complicated by infection. This method provides for three essential things: immobilization of the bone, rest for the wound and free drainage. If these are not attained, the whole point of the treatment is lost. The dressings are changed infrequently and the bone is not irritated by repeated change of apparatus. There should be complete drainage with no possibility of damming back or formation of pockets of infection.

Chemotherapy

As has been mentioned, heavy scar tissue usually surrounds the parts in old, ununited fractures. In this scar tissue there are likely to be islands of walled-off infectious material if the nonunion has been due to infection. For repair in such cases, the application of one of the sulfonamide products directly to the wound has been effective. Oral or intravenous administration of any of these compounds is ineffective, since by neither of these routes does the drug reach the parts which are likely to hold infection. In powdered form, however, it may be evenly distributed throughout the wound (up to 10 gm.).

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CHAPTER III

MECHANICS OF OPERATION

THE man who has many tools is not necessarily a skilled mechanic, but a skilled mechanic usually has all the necessary implements to facilitate fine work. Bone surgery calls for great mechanical ingenuity as well as skill; it might be compared to cabinet-making under extremely difficult circumstances. The bone may be held in malposition by the surrounding tissues, and the deformity must be overcome before the fragments can be fitted together properly. A complete range of sizes of bone instruments must be at hand. One cannot expect to handle a femur with an instrument made to fit a radius or ulna, or vice versa. Motor-driven instruments make for less time-consuming, and more accurate, work but one should not start an apprenticeship using motor-driven bone instruments while operating in a difficult case. Skill should be developed by practicing on fresh bone which can be obtained from the kitchen of almost any institution feeding large numbers of people. A carpenter's clamp holding such a bone on a workbench can be the laboratory, and a considerable degree of facility in use of these instruments can be gained in this way. Irreparable damage could be caused by motor-driven instruments in the hands of surgeons unskilled in their use and the patient on the operating table would have no protection against such lack of skill.

Cleansing the Parts

Soap and water applied with sterile gauze is the most effective cleansing agent preparatory to operation. This cleansing should be thorough and vigorous, and should include a wide area above, below, and around the site of operation. On an arm or leg the scrubbing should be circumferential, and should give a wide area of sterile preparation. If possible, this scrubbing should be done the day before operation; if thought advisable, it should be repeated just prior to operation, the parts being covered with sterile dressings and sterile towels until the patient comes to the table.

The patient should be properly placed on a suitable table, in such a way that the surgeon can control the movement, the traction

and the angle of the limb during operation, without disturbing the sterile linen with which the patient is draped. The details of preparation should be supervised by the surgeon personally before the patient is draped; otherwise difficulties will occur which may lead to disarrangement of linen and contamination of the wound. Much annoyance and hazard can be avoided by proper preliminary supervision. Assistants are not always completely informed as to what the chief may intend to do, and often do not make the proper preparation or do not have the patient fixed in a way that will facilitate operative procedure and manipulation.

Draping

The draping of an extremity for operation is much more difficult and much more technical than is draping for an abdominal or spinal operation and careful draping and proper fixation of linen are of particular importance in any surgical procedure wherein manipulation during operation is necessary. It calls for no mediocre skill properly to apply and fix the operative linen. The skin is washed with ether and this is followed with application of iodine or merthiolate (alcohol solution) which is washed off with alcohol, 70 per cent. This preparation should be made before linen is applied. Towels should be placed well above and below the site selected for incision, leaving plenty of room to enlarge the incision if necessary. It has been found of advantage to drape one towel, starting from the top, lapping it under the extremity and fastening it with towel clips, starting the next towel from beneath and fastening it above, with both edges at the same level. Care must be taken that the towels do not come in contact with any unsterile surfaces while being applied. The sheets are then placed around, above and below, and across the table, and are fixed to the patient's skin with skin clamps in sufficient number to prevent their being pulled out during manipulation. The sheets should be placed loosely enough to permit manipulation without interference.

If careful attention is given to these details prior to surgical procedure, many heartbreaks for both patient and surgeon will be averted.

Incision

The incision must be large enough to permit thorough and complete exposure of the parts which it will be necessary to manipulate. Ununited fractures cannot be handled through a small incision. The difficulties of overcoming contracture and malposition, and of fitting

the ends of the fragments together, make ease of access essential, and this cannot be attained while the ends of the fragments are bound down with fibrous tissue.

Muscles should not be cut, either longitudinally or transversely. Access to the bone should be gained between the muscle planes. All scar tissue should be removed when and where found. Periosteal elevators should be sharp enough to penetrate between scar tissue and bone. The fragments should be completely freed to permit inspection and manipulation. Until this is done it is impossible for the surgeon to decide the best method of approximating and holding the fragments. The consistency of the bone in the fragments has much to do with the choice of method to be used in maintaining them in position. Bridging a long gap with a bone graft is always a hazardous undertaking; unless the bone graft can be fastened solidly to the host bone, and unless the host bone is solid enough to maintain this fixation, there is no use proceeding with a difficult task which does not offer reasonable assurance that it will achieve its purpose.

Choice of Method

Innumerable methods have been advanced for retention and fixation of ununited fractures. No method will fit all cases. When the fracture has been exposed, the mechanics of the situation must be evaluated and a method devised to fit the particular case. Several methods are here described which have as their object the fixation of fragments. All these methods contemplate introduction of a bone graft in one form or another, because it has been well proved that an autogenous bone graft will promote union when simple fixation will fail. The type of graft varies, depending on the type of fracture and on the bone or bones involved. One cannot put an inlay graft of sufficient strength in the radius or ulna to act as an immobilizing splint, but this can be done in the femur or tibia. Therefore, a method which would apply to a large bone might not apply to a smaller bone. It may be advisable to use a combination of fixation by a nonirritating metal plate, properly applied, with a graft to serve as a bridge for the redeposition of bone. The plate acts as fixation apparatus and the bone as a stimulating bridge to promote formation of new bone. If a graft alone is used, it has been well demonstrated that the massive bone graft has many advantages over the small graft, but massive grafts are not applicable, especially where the bones are small, because there is not sufficient foundation in the host bone. The fixation apparatus must supply enough strength to reinforce the graft and the host bone, thus to resist the pull of muscles that tend to

produce overriding, angulation, or torsion, and in most cases all three. Under these circumstances a thorough consideration of the mechanical as well as the surgical factors is necessary before the method of application is decided on for the particular patient who is on the operating table, before the surgeon, at the moment.

Principles of Applying Internal Fixation

There are two separate and distinct objects to be attained in any operation for ununited fractures, and these must be kept in mind constantly when selecting the method to be used: (1) firm and constant immobilization; (2) provision of tissue on which new bone will form across the bone defect. In order to achieve these objects, the condition of the host bone must be taken into account. Also, the closer the ends of the fragments can be brought together, and the more tightly they are made to fit end to end, the less strain will occur on the fixation apparatus. The approximation of fragments will cause shortening of the bone in almost every instance, but if the shortening is not enough to interfere with the ultimate function of the extremity, it is better to bring the ends of the fragments close together rather than to try to bridge a long gap between them.

This consideration may be influenced by the site of the proposed graft. The circulation in the lower leg is poor and a graft may not be as successful here as in the femur or the arm. Shortening in the leg is not a serious disability, inasmuch as it can be compensated for by a lift on the heel of the shoe. It is better, therefore, to have some ultimate shortening in the leg than to risk bridging too wide a space. In the femur, the large muscles put so much strain on a graft bridging a long gap that it is difficult to hold it in position. In the arm, shortening makes no difference in function either in the humerus or in the forearm if both bones are shortened equally. The humerus can be shortened with impunity and the result is much better when this is done. However, in the forearm, if one bone is united and the other ununited, it is best to try to bridge the gap in the ununited bone and restore the normal relation between the two bones.

As stated before, no one method can be advised and, as a matter of fact, it is frequently impossible for the surgeon to decide until the ends of the fragments are bared and the condition of the bones and surrounding tissues is evaluated, what operation will best suit that case. A number of methods are here described and illustrated; these can be used as demonstrated or can be combined in any way that will fit the case at hand. The surgeon's ingenuity should be directed toward the accomplishment of two important factors: firm fixation,

and a supply of bone to act as a stimulating agent for the reconstruction of new bone across the gap and around the fracture.

It is again emphasized, therefore, that close approximation of the ends of the fragments is necessary, with firm fixation by means of massive graft or a plate, or both, and complete transfixation by screws of the graft or plate. In order to prevent pivoting it is best to insert the screws—metal, ivory, or bone—at various angles rather than in the same plane. This stabilizes the fragments much more effectively. It should be done even at the expense of having the screw heads at a little angle with the surface of the plate or the graft.

Kind of Screws for Fixing Graft or Plate

In the armamentarium there should be machine-thread screws of bolt type with threads cut close up to the head. The drill should be about seven sizes smaller than the diameter of the screws in the outer circumference of the thread. If it is a tap-end screw this will allow a good bite into the bone. If a bone or ivory screw is used the tap should be exactly the same size as the screw, and the drill seven sizes smaller. Care must be taken not to allow the drill to "wobble" as it is put through the bone. The drill must be true and the holes it makes must be true; otherwise a cone-shaped hole is made, with the wide end toward the surgeon, and the threads will not hold. It is much easier to make a true cylindrical drill hole with a motor-driven instrument than it is with a hand-driven instrument, which is constantly pulled out of line by turning the crank on the drill.

Double Onlay Graft

It has been well proved that the long, strong, firmly fixed graft produces better results in the healing of ununited fractures than any other method. The preparation for such a graft is a major accomplishment, both preceding operation and at the operating table. The ends of the fragments should be thoroughly exposed. The fibrous tissue should be completely cleaned away, leaving raw, bleeding bone. The amount of resection necessary at the ends of the fragments is a matter of judgment at the time of operation. H. Jackson Burrows does not feel that complete resection of the ends of fragments is always essential. However, it is necessary in most cases to remove the fibrous tissue between the fragments in order to manipulate them into proper alinement and rotation and to supply a suitable bed for the graft. When this has been done it can be judged how much resection is necessary to bring the fragments together if apposition is de-

sired, and how large a graft can be secured, in length, width and strength, from another bone in the patient's body, usually, of course, an unaffected tibia if such is available; if not, a long section of rib frequently will suffice.

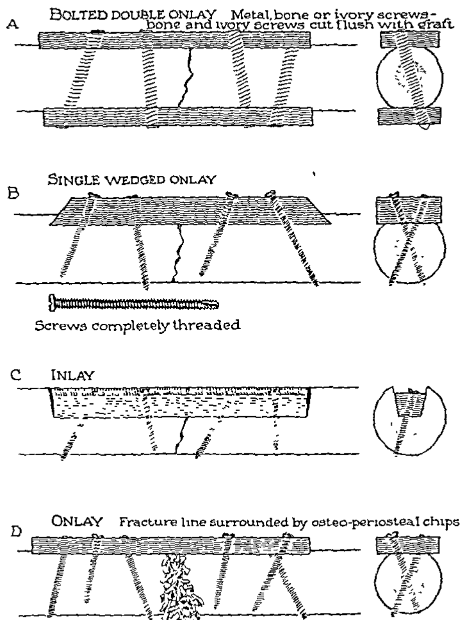


Fig 2—Other methods of bone graft.

An onlay graft should be applied tightly to the host bone and, if used, it may be necessary to cut a flat surface on the bone. The medullary surface of the graft should be firmly fixed against the

cortical surface of the host bone (Figs. 1, D, and 2, D). A double bone graft, that is, one graft on each side of the host bone, has been found by J. S. Speed, of Memphis, to be the best form of fixation that can be made by an onlay graft. It presses the bone from both sides and the screws which penetrate the full diameter of the host bone and both grafts practically bolt the fragments together and hold them between the two healthy surfaces of the graft. This supplies the two desired objectives—the supply of new bone to bridge the gap and firm fixation (Fig. 2, A).

The screws which hold the grafts together should penetrate the bone at varying angles, so that they will not be in the same plane or in the same line. It will be readily appreciated that this type of graft is difficult to apply; exposure must be wide and thorough and retraction must be complete. The grafts must be held by suitable bone clamps while screws are being inserted. If there is the slightest bit of motion while a drill hole is being made, or before a screw is completely through the bone, the screw will not pass through the drill hole, and great difficulty will be experienced in relocating it without weakening the graft and the bone. Application of the double onlay graft is a major surgical procedure; to become qualified to use this method the surgeon requires a considerable period of practice.

Single Onlay Graft

The same principles are used for the single onlay graft as for the double, except that it may be found advantageous to cut the ends of the graft in the shape of a wedge, cutting a female member of the wedge where it fits into the host bone at each end. Making a bed and fastening the wedge in at the ends takes up a considerable amount of torque and strengthens the hold of the graft on the host bone.

After the ends of the fragments have been freshened, the graft is placed overlying both and bridging them and, if they are held firmly toward each other during the process of screwing the graft fast, additional protection is given so far as angulation and rotation are concerned. If bones that are subject to torque by muscle pull, such as the ulna and radius, are held in this way, a firmer locking between the graft and the host bone results. The screws penetrate the graft and both sides of the cortex and are also put in at varying angles (Fig. 2, B).

The single heavy onlay graft is probably the method of choice when it can be used. The graft should be as heavy as possible, and should fit snugly. If there is opportunity to place two grafts of this

type across the same fracture line, the chances of securing union will be enhanced. It must be remembered, however, that these grafts enlarge the circumference of the bone, and it may not be possible to close the tissues over the bone without great tension if the circumference is enlarged too much. Therefore, care should be used in estimating the application of this type of fixation.

The Inlay Graft

The inlay graft is of advantage in treatment of fractures of larger bones, such as the femur and tibia. It opens a considerable gutter on both sides of the fracture and, if a proper bed is made and the graft is cut in the proper way, very close union can be attained between the graft and the host bone. The bone fragments are held together firmly with a four-prong bone clamp or some other instrument which will firmly grip both fragments and hold them in line and, with a single small circular saw, a gutter is cut in one side of the cortex, extending through into the medullary cavity. The sides of this gutter which face each other are made sloping in a partial wedge, with its point toward the medullary canal. The graft is cut at the same angle so that it is wider at the cortical-periosteal surface than at the medullary surface. The graft is then laid in the gutter and driven down with a blunt instrument, so that the sides of the graft are gripped by the bone and the graft is countersunk below the surface of the cortex of the host bone. The whole length of the graft is thus supported by its being wedged into the host bone, which gives extremely firm fixation.

Screws are then driven through the graft and through the cortex of the bone on the opposite side. The smaller the screws used, the less substance of the graft will be penetrated, and consequently less weakening of the graft will occur. An effort should be made not to put the heads of the screws in the same line, but to stagger them so that the hazard of splitting will be minimized. The fact that the heads are not flush with the graft will not jeopardize the result (Fig. 2, C).

A long graft set in this way, and held by small, nonirritating metal screws, gives extremely firm fixation and this is probably the operation of choice for such bones as the tibia and femur. If there is a gap, this offers an excellent method of bridging it. Other parts of the gap may be filled in with loose bone chips of osteoperiosteal type, packed in tightly between the ends of the fragments and around the graft.

Intramedullary Dowel Inlay Graft

This is a combination of the inlay graft and the intramedullary dowel graft. It is extremely difficult to insert the intramedullary dowel graft into the medullary cavity from the ends of the fragments and to drive it in snugly enough to hold in close contact with the host bone; there is always some residual angulation movement. If the dowel can be driven in snugly it is a good form of internal fixation, and it is possible, by making a slot in the lower end of one fragment, to drive the graft into the medullary cavity of the opposite fragment and then to countersink the graft into the slot cut opposite it[2] (Fig. 1, A). The part of the graft which lies in the slot is fastened with screws in the manner before mentioned. If there is a gap to be bridged, the remaining defect can be packed full of bone chips removed from the same site from which the graft is taken; or if the host bone is of good quality, such a graft may be cut from above and driven down through the medullary cavity, using chips from above the site of removal of the graft to pack into the defect.

Metal Plate Fixation, Plus Osteoperiosteal Grafts

In some cases it may be impossible to find a suitable bed for the application of a long bone graft. A long, six-hole, or eight-hole plate of nonirritating metal may serve as a fixation apparatus, with the bone graft supplied in the form of an osteoperiosteal graft or chips. It is extremely important to use a plate which is of minimal thickness but of sufficient strength to resist breaking under the strain put on it by the muscles. The longer the plate and the more screws used, the better so far as fixation is concerned. The screws should be put through at a slight angle. They should be of machine-screw type with tap ends. The drill should be seven sizes smaller than the outside diameter of the thread, and a screw-holding screwdriver should be used if possible. The screws at the ends of the plate play an important role because, at these points, more leverage is exerted by the muscle contracture than is the case closer to the site of fracture. It is therefore essential that all the screws transfix the plate to the bone.

Vitallium is the most nonirritating material so far discovered for use in bone surgery. However, it is a cast metal and the screws and plates may be brittle and break under cross strain. Stainless steel plates and screws, high chrome (19 per cent) low nickel (9 per

cent)* are completely satisfactory as to strength and nonirritating qualities.†

A plate should not be used to bridge a gap even though the gap be filled with osteoperiosteal graft; a heavy bone graft is more efficient in such cases. A plate may be used to stabilize the fragments either in the presence of a long graft or when the fragments are approximated, chip grafts being placed between and around the ends of the fragments. After the plate has been firmly fixed and the fragments seem to be perfectly solid, small bone chips should be closely packed between the ends of the fragments if there is any place in the circumference of the host bone where there is no bony contact. The fracture itself should be surrounded by a multitude of small bone chips for at least ½ inch (1.3 cm.) above and ½ inch below the site. The tissues should be drawn together as snugly as possible to hold the bone chips in close contact with the bone. The chips can be taken from any other available bone, such as the surface of the tibia or from a piece of resected rib which has been placed in warm physiologic salt solution until used.

Wedging Operation

It is probable that failure of union sometimes occurs as a result of improper or inadequate contact between the ends of fragments and, in a case of fracture of a bone the size of the humerus, femur or tibia, it may be found advantageous to supply this close bone contact over as great a surface as possible. Wedging the ends of the fragments accomplishes this to a greater degree than any other procedure. The end of one fragment is cut in the shape of a male wedge; the end of the other in the shape of a female wedge (Fig. 1, B). This is a nice piece of cabinet work and must be done accurately and carefully. *The object of the procedure is twofold: (1) to provide* wide bony contact and, (2) to prevent torque. If the two wedges are held together firmly, with pressure exerted between the fragments, both objectives are accomplished. If pressure is not achieved, then of course the whole point of the procedure is missed.

In this operation careful estimation of the shape of the ends of the fragments must be made before deciding in which plane to cut

* Joseph E. Becker, maker of precision instruments, 622 W. 168th Street, New York.

† Plates and screws of stainless steel 18-8-S-Mo. These can be secured through Harvey Pierce, 17th and Chestnut Streets, Philadelphia; or the Zimmer Manufacturing Company, Warsaw, Indiana. (Two types of metal should not be inserted into the same bone; they may set up an irritating electrical reaction.)

the wedge and how it will fit into the other fragment. Very thin, razor edge chisels should be used; clumsy, thick or dull chisels cannot accomplish the purpose. The chips that are removed must be very small or there is danger of breaking off a piece of bone or splitting the fragment. This operation also should be tried out on fresh, uncooked animal bone to establish the technic. The ends of the fragments are often friable, and extreme caution will be necessary to avoid injury to the sides of the wedge, which would prevent proper fitting. After the surfaces have been cut and properly fitted, they can be held in approximation by a wire which crosses the site of fracture and is put through drill holes at a considerable distance each side of the fracture. Two wires at different planes may be used if there is any question about the firmness of fixation. The wire is twisted like a turnbuckle, to pull the ends of the fragments into close approximation. Ordinary baling wire, called "malleable iron wire," or "stove wire," which is the same thing, will serve better than any other type, but any wire which will stand a strong twist will suffice.

If application of a plate is more convenient, the fragments can be so fixed, but it is advantageous to hold them together snugly with a wire running from top to bottom, pulling the fragments together while the plate is being applied. This is preferable to having an assistant push the fragments together, as it will be found that some motion occurs in the course of applying the plate, and the fragments can be held in much closer apposition by mechanical means.

Mortise and Bevel Fitting of Fragments

In some cases in which the ends of the fragments are of suitable shape, the ends may be cut obliquely, or in the form of a step or mortise. If the fracture was oblique, and the edges are rounded off but still oblique, freshening these edges so that they can be brought end to end sometimes will serve as the best form of contact. This is more easily accomplished than the wedge operation because the angle can be estimated, and the saw will cut a straight edge which should fit against the straight edge of the opposite fragment. The two edges may be held in firm apposition by one or more screws inserted at an angle to the obliquity of the fracture. Two screws are always better than one because pivoting will be avoided.

If the ends of the fragments seem to approximate the shape of a step in their obliquity, the end of each can be squared off and a flat surface made to fit against the other (Fig. 1, C). These can be held with two screws and this makes a very firm union if the quality of the bone is such that the screws will hold. In bone which has

undergone calcium absorption the screws will not hold firmly and this type of fixation had better not be attempted in such cases.

Telescopic Fixation

In some cases, the presence of a long point on one fragment and a more or less square one on the other offers an opportunity to insert the long end into the medullary cavity of the other fragment and, while this leaves a jog in the bone, if the long axis of the fragment is correct it makes a very satisfactory form of contact (Fig. 1, E). Sometimes the fragments can be held very firmly by cutting a bed for a steel plate in the cortex of one fragment and screwing the plate to the outside of the cortex of the other. Or a bone graft can be used, cutting a slot in one fragment and making an onlay graft on the other.

If a plate is used, an osteoperiosteal graft should supplement the plate and carry tightly packed bone chips around the defect.

Drilling

If nonunion has occurred but the fragments are in good position and there is little or no space between them, drilling sometimes will produce a satisfactory result; it is used more frequently in cases of delayed union than in those of nonunion. Drilling of the fragments in many directions, at many angles, opens channels in the bone and in the fibrous tissue surrounding the ends of the particles, lays down bone particles between the fragments and in the fibrous tissue, and sometimes acts as a stimulant to circulation and to production of bone. The drilling should be thorough and the ends of the fragments should be penetrated at many angles, from different directions, and the holes should penetrate above and below the fracture. This causes hemorrhage, and the reaction simulates the production of a fresh fracture. However, if there is any major defect, or if the fragments are not in good position, usually drilling is a waste of time unless there is some other indication for doing it.

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CHAPTER IV

TREATMENT AFTER OPERATION

TREATMENT OF INFECTION FOLLOWING OPERATION FOR UNUNITED FRACTURE

IN spite of the greatest care, the most rigid surgical technic and the most thorough preparation, infection may occur following operation for ununited fracture, especially if the nonunion was due to compounding and infection. Following surgical operations of the type under consideration, it is best not to dress the wound at all until the stitches are removed, but the clinical course of the patient should be watched carefully for at least two weeks after operation. The temperature and the leukocyte count should be closely checked, and any complaint of pain should be given serious consideration. There should be little pain following this type of operation if the fragments have been firmly fixed and there is a minimal amount of swelling. A complaint of extreme pain, especially throbbing pain, particularly if accompanied by an increase in temperature to more than 100.5° or 101° F., and a rise in leukocyte count to more than 12,000 or 14,000 cells per cubic millimeter of blood, call for immediate opening of the dressings and inspection of the wound without disturbing the external fixation. If there is redness, swelling, bulging around the sutures, induration and tenderness, the wound had best be opened wide and free drainage instituted. After the pus has been allowed to escape for twenty-four to forty-eight hours the wound should be packed with vaseline, left wide open, and treated according to the Orr method. It can be dakinized, although it is extremely difficult to do this when an extremity is encased in firm plaster or a splint. The ends of the fragments must not be disturbed, and the graft, plate or other apparatus for internal fixation must be left in situ. Even in the presence of infection, if there is thorough drainage and rest for the wound, the fracture may heal, and whatever is unacceptable to the bone will be loosened and can easily be removed at some future date

Chemotherapy can be used for any general infection and one of the sulfonamides can be used within the wound if the infection seems rampant; ordinarily, however, the less manipulation the better so long as thorough drainage is established.

GENERAL PRINCIPLES OF TREATMENT AFTER OPERATION FOR UNUNITED FRACTURE

Great care must be taken to see that the fixation dressing applied subsequent to operation for an ununited fracture is smooth fitting and firm, without causing pressure on bony points, and that it is carried far enough above and far enough below the site of fracture to ensure not only immobilization from the standpoint of preventing angulation, but also from the standpoint of preventing rotation. It is impossible to immobilize a cylinder (bone) covered with soft masses (muscles, blood vessels, nerves, and skin) within a cylinder of hard material (plaster). Rotation must be prevented. If one is immobilizing a fracture of both bones of the leg after operation, the knee, as well as the ankle and foot, should be included in fixation, and the joints above and below the fracture should be fixed in such position that the angle will control any tendency toward rotation of the fragments. The same thing applies to fracture of both bones of the forearm. If the elbow is fixed at a right angle, the cast should extend far enough above the elbow to prevent rotation of both bones.

Frequently nonunion in cases of fracture of the humerus is due to the difficulty of preventing rotation as well as angulation of the fragments, and here of course the body and the shoulder must be included in fixation, as well as the elbow and forearm.

Compression Dressings

There is always ooze from bone wounds. The suturing of these wounds should be done in such a way that this ooze can be permitted to escape through spaces in the closed incision. Therefore, interrupted sutures in skin, muscles and fascia are preferable to continuous sutures.

A large mass of dressing over an operative bone wound is always advisable. Over this dressing, which should be applied smoothly, a compression bandage of the nonrubber elastic type should be used and, especially in wounds of the leg, a second dressing of abdominal pads, with a second compression of the same type of bandage, will be found advantageous. The dressing itself, if large enough, will act as a fairly good temporary splint and, if the injured member can be

placed in an auxiliary splint, either molded plaster or a Thomas splint, it may be unnecessary in certain cases to apply circular plaster immediately following operation. However, the surgeon must be guided in his judgment by the firmness of fixation obtained at the time of operation. He should take no chance of having cross strain or injury undo the results of surgical operation.

In many cases, permanent splints cannot be applied immediately following operation, because of the necessity for applying massive dressings and the fact that swelling is likely to occur. Temporary, but thorough and competent, immobilization should be established before the patient leaves the operating table, with full knowledge that permanent dressings will have to be applied after the stitches are removed and the wound is healed.

Permanent Immobilization

Permanent immobilization, which is applied after the stitches are removed, should be put on in such a way that it will achieve real fixation and will be comfortable over a long period of time, certainly not less than eight, and possibly twelve to sixteen, weeks. Nothing so far devised can take the place of circular plaster, well applied. Skintight plaster is preferable in some cases, and this certainly furnishes the best form of immobilization. The application of skintight plaster calls for care and dexterity. It should be deferred until all swelling has subsided and thorough healing of the wound has been established. It is possible to put these plaster casings on without causing pressure on bony points, but it is an extremely difficult procedure, and bony points should be protected by a pad of soft wool felt, ¼ inch (0.6 cm.) in thickness. In a weight-bearing area, below the knee for instance, where a walking caliper cast is to be applied, it will be found that a band of soft wool felt drawn snugly around the upper end of the tibia, with the edges sewed smoothly together where they meet, will add greatly to the comfort of the wearer, and a cast can be put on snugly around this point and maintain its weight-bearing function.

Sheet Wadding

Sheet wadding is a poor form of padding, because after the cast has been worn for some time it will be found that the wadding has rolled up and, if there is any atrophy of the muscles underneath the cast, the cast will become loose much more readily than if fitted over snug felt or skintight plaster. Each patient must have a permanent immobilization dressing which is made for his particular fracture.

If this is not done, the result of the serious operative procedure endured by the patient, and by the surgeon also, may be endangered and brought to an unsuccessful conclusion.

Inexperienced persons should not be permitted to change casts. Fractured limbs must be handled gently and supported well above and well below the site of fracture whenever the cast is changed. This is pointed out in the following paragraphs on individual fractures, and it cannot be repeated too frequently. In many cases after a successful operation has been performed, its purpose has been defeated because of subsequent improper handling and improper fixation. It is true that the application of fixation, whether it be traction suspension, or splints, or plaster casing, is a nuisance for the surgeon. Nevertheless, the details of after treatment are fully as important as the operation itself and, if the operation is worth while, careful after treatment is also worth while, and should not be left to the hands of inexperienced or careless individuals.

Sutures and Ligatures

Operative procedures in bone and joint surgery call for as delicate technic as does surgery of the eye or of the nerves. The introduction of foreign material into the wound should be kept at a minimum, and choice of material which is as nonirritating as possible is important. If silk is used it should be very fine silk, and there should be no more ligatures than are absolutely necessary. Some surgeons use nothing but plain number 0 and number 00 catgut for ligatures and sutures. A single square knot is tied—never three knots—and the suture is cut close to the knot. It is unnecessary to clamp tiny, individual blood vessels; a little traction will check most of the ooze. Larger blood vessels may be ligated but there should not be a mass of tissue distal to the ligature. Tension on tissues, crushing tissues, and tight ligation should be avoided. Gentleness, sharp dissection, and attention to the infinite detail of fine surgical technic will pay substantial dividends in results to both patient and surgeon.

CHAPTER V

LOCAL ANATOMIC TREATMENT

THE CLAVICLE

THE clavicle is one of the most infrequent sites of nonunion. If nonunion occurs here it is usually because of compounding or severe disruption. The clavicle has an adequate blood supply, it lies immediately under the skin, and it is not a difficult bone to approach. However, if there is severe scarring immediately over the bone, this cicatrization must be replaced by normal epithelial covering before any attempt is made to fill in the defect in the bone. This may necessitate a flap graft, which usually can be turned up from the chest.

The incision or approach should be made parallel to the lower half of the clavicle, opposite the lower edge, and the skin should be retracted upward. The incision should not be made directly over the bone. Inasmuch as the clavicle is a doubly curved bone, the outer third of which lies immediately over the plexus of nerves and blood vessels which run between the clavicle and the first rib, the contour of the bone must be restored to prevent pressure on the underlying structures. A section of rib sometimes serves best to fill in the defect, and is strong enough to restore the bone to normal function when healing has taken place. It depends to some degree on the location of the defect as to what method should be used. In any event, the graft should be fastened to the fragments securely at each end, and the graft shown in Fig. 2, B, should give the greatest stability, although it may be that a graft forced into the medullary cavity of each fragment will serve as well or better.

Fixation Dressing

The dressing should be applied with a well padded plaster figure of eight around the front of each shoulder, across the back, extended down onto the chest in the form of a jacket. It should be put on with the patient supine on a very narrow metal plate, placed longitudinally between the shoulder blades under the spinal column, with the shoulders thrown well back. The plaster dressing should be brought

forward over the clavicle on each side, and this area should be padded to avoid pressure on bony points.

Length of Time of Immobilization

Ten weeks is probably the minimal time within which one could expect any bone graft to unite sufficiently to permit any degree of freedom. This is true of the clavicle, but digital and roentgenologic examination should determine whether the apparatus for immobilization should be removed at this time or whether a means of less rigid immobilization should be applied. Roentgenograms should be taken with the patient on his face to bring the clavicle closer to the plate and should be made from at least two angles to determine the amount of callus present and whether the graft is viable.

THE HUMERUS

The humerus, especially in its lower third, is a favorite site for nonunion. This is due to the fact that the supporting muscles, when compared with other muscles controlling the long bones, are not extremely strong or active. It is very difficult to put on a dressing to prevent motion of the upper fragment, which is controlled by the great muscles attached to the chest wall and the back. Every effort of the patient in moving his body transmits a pull on the upper fragment. The lower fragment, encased in a rather fixed dressing which hangs away from the body, does not follow these motions and, as a consequence, there is more or less constant mobility of the fragments; the weight of the dressing pulling away from the body distracts the fragments.

The object of any operation for nonunion of the humerus, then, should be to hold the fragments toward each other, and any shortening which may occur is of no importance so far as return of function is concerned. If the fragments can be held in close end-to-end contact there is little danger of displacement, except possibly slight angulation or rotation, and this is not difficult to overcome.

Incision

The incision should be made on the outer surface of the arm, between the biceps and triceps muscles, just at the posterior edge of the biceps. The radial nerve is somewhere in this vicinity, its proximity depending on the location of the fracture, and it should be found and freed before the fracture is approached. If the site of fracture is involved in scar tissue, the nerve should be found above and traced down to the site of fracture and, if then lost, should be ex-

posed below and followed upward. With slight tension, the remaining portion of the nerve usually can be freed from the scar tissue without injury, by carrying the scalpel with the point along the periphery of the nerve and the cutting edge point obliquely away from it. When the nerve has been freed, the bone fragments should be completely exposed and the scar tissue dissected out (Fig. 3).

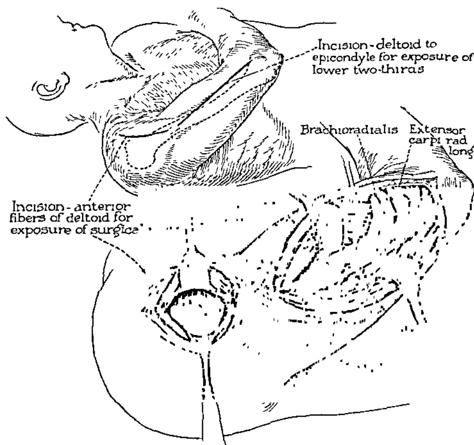


Fig. 3 —Exposure of the humerus.

Special Treatment

As has been said before, length of the humerus is not so important as length of some other bones. Nonunion frequently occurs as a result of distraction, simply from the pull of the weight of the arm. Therefore, after removal of the scar tissue, the creation of wedge contact, as is shown in Fig. 1, B, should be considered. This procedure, when properly carried out, has given 100 per cent good results in ununited fractures of the humerus. It is important to hold the fragments together by some method of support to overcome the drag of the forearm, which may pull the lower fragment away from the upper and, to this end, a wire loop inserted at some distance above

and below the site of fracture is advised, even though a metal plate or bone graft may be used in addition. It is unnecessary to use either metal plate or bone graft, although chip grafts are placed around the fracture to stimulate formation of new bone.

Bridging Large Defects

Sometimes a large defect in the length of the humerus is found, possibly extending down to the forearm. Shortening of the arm to bring the fragments together would interfere with both function and

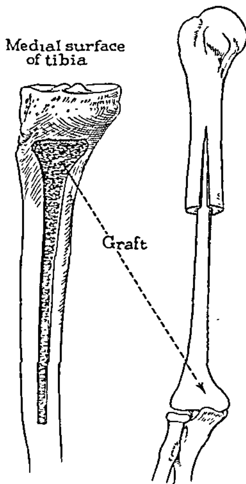


Fig. 4—Graft with wide end taken from tibia for defects of the humerus that extend to the elbow.

appearance. In such cases a long bone graft, attached at one or both ends, may be inserted with considerable hope of a successful result. Firm fixation of the graft must be secured and, when it is necessary to use a graft attached at only one end, it is advantageous to split the longer fragment, push the bone graft into the medullary cavity,

stretch the soft tissues of the forearm to their limit and jam the opposite end of the graft into the medullary cavity of the other fragment. If the defect extends down to the elbow, the graft is cut from the tibia in such a way that it will make contact with the upper end of the ulna or radius, or both. A graft with a very wide end can be removed from the tibia. The graft is extended upward to the head of the tibia and is curved outward at the top, so that it removes almost the entire width of the bulge of the head of the tibia just below the knee (Fig. 4). With this end of the graft against the upper end of the radius and ulna, and the upper end of the graft forced within the split upper fragment of the humerus, firm contact is secured. Screws are then inserted through the two edges of the humerus and through the graft, to hold it firmly in place.

Immobilization

If the fragments can be fastened securely they require very little immobilization. A sling placed around the forearm, extending from the base of the fingers to the elbow, will suffice. This, with a small pillow surrounding the humerus, gives gentle support for the weight of the forearm and the lower fragment. Neither an airplane splint nor rigid immobilization in a cast is necessary. In many cases immobilization will be sufficient if two short, coaptation splints, padded with felt, are applied anteriorly and posteriorly over the biceps and triceps muscles.

If the elbow is not rigid, some motion of this joint may be allowed. There is usually severe disability in the shoulder following long immobilization and, to avoid this, the hanging cast described by John R. Moore will permit motion of the shoulder if the fragments are held snugly, although it fixes the elbow at right angles and extends from the wrist to the axilla. This cast must be firmly supported in a sling if there is enough weight to distract the fragments. In some cases a pillow is simply pulled tightly up into the axilla, the ears of the pillow slip are pinned around the clavicle and acromion, and the pillow is prevented from slipping by putting a strap under the opposite arm, the ends of the strap being brought across the chest and back to the shoulder, and pinned to the pillow slip. The pillow slip is then pinned around both upper and lower arm, and a sling is applied to support the weight. The pillow slip should be pulled tight over the pillow and pinned, and this gives more even and firm support than if the pillow itself were pinned. The pillow should be of proper consistency, neither too thick nor too thin, and should be stuffed with material which is resilient (Fig. 5).

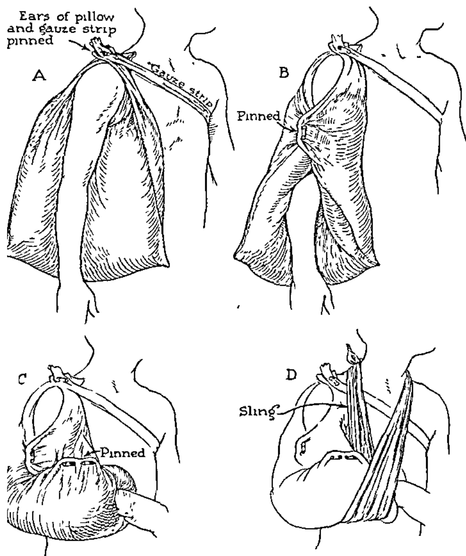


Fig. 5.—Use of pillow and slip to immobilize humerus. A, Pillow secured in axilla; B, slip pinned about humerus; C, slip pinned about flexed forearm; D, sling applied.

Time of Healing

If the fragments have been brought snugly together with a broad contact surface, and if the arm is adequately supported, these fractures heal more rapidly than any other ununited fracture. Excellent results should be obtained, so far as union is concerned, in from eight to twelve weeks. In cases in which nonunion has existed for as long as two years, complete and solid bony union is obtained in eight weeks, especially with the wedge operation. However, if the fragments are not held snugly, callus will not bridge the gap between them. Firm internal fixation is of utmost importance, because no

dressing will accomplish much in the way of fixation of fragments. During the period of healing some motion should be instituted in the shoulder by having the patient lean toward the side of injury, with the arm swinging into abduction. This can be done with the sling in place, and in this way the shoulder may be kept in motion and much subsequent disability will be prevented.

THE FOREARM

The repair of ununited fractures of the forearm can be classified as among the most difficult surgical procedures. There are a number of reasons for this: The multiplicity of the muscles, the angles at which they pull, and the fact that they are among the most irritable from the standpoint of contracture of any in the body, all play a part. The radius moves around the ulna on joints at each end. The muscles that control this rotation are short, strong, and active. The fragments must be retained not only in proper rotation, but angulation must be prevented in order to allow rotation to occur normally. Any shortening of one bone, without comparable shortening of the other, is reflected in loss of function because of mechanical disturbances in the joint between the radius and the ulna at the lower end. Inasmuch as the muscles of the forearm are concerned in motions of dexterity of the hand and wrist, and rotation is also concerned in the function of dexterity of the hand, there are many mechanical and functional problems to be faced. Once contracture of these muscles and adhesion of the tendons has occurred, the mere replacement of bones in normal position will not produce a satisfactory result. Therefore, the preliminary treatment of the soft tissues is more important than the surgical procedure and sometimes many months of physical therapy must precede surgical operation.

The operative difficulties are great. Fibrosis and contracture of the muscles, and entanglement of the interosseous membranes occurring around the fragments, may hold the bones in abnormal positions which are almost impossible to overcome without completely freeing the bones from their muscle attachments and from the interosseous membrane. The bones are small and, if nonunion has existed for a considerable time, the cortex is thin and fragile, which necessitates application of a long and firm support. It is almost impossible to overcome a long-existing shortening in the forearm because the bone fragments will not stand the pressure of stretching the muscles and fascia. For this reason, shortening is preferable, especially if nonunion of both bones exists.

Incision

Incision over both radius and ulna should be made slightly to one side of the place where the bone lies closest to the skin, not immediately over the bone. Care should be taken to follow the intra-

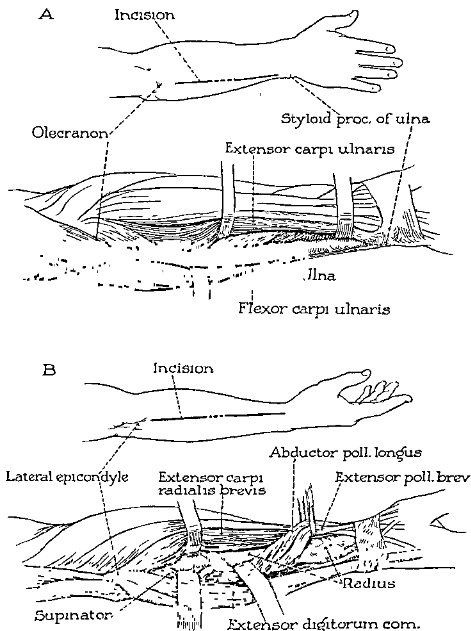


Fig 6.—Exposure of, A, ulna; B, radius.

muscular planes. The tendons and muscles should not be traumatized or cut (Fig. 6). The fragments should be completely freed of all scar tissue as the operation progresses.

Internal Fixation

When the ends of the fragments are inspected a plan of procedure can be outlined. As stated before, shortening by cutting off the ends of the fragments and bringing them into alinement and proper rotation with each other is usually the best procedure. Clamps that are small enough to hold the radius and ulna firmly should be used; without these the bones cannot be held satisfactorily. Usually the wounds for both radius and ulna should be opened at the same time, and thus both bones can be shortened in the amount necessary to bring both fragments of both bones into proper relation and rotation. It is advantageous to fasten the ulna first and, after it is firm, to adjust the radial fragment. It will be necessary to grasp both upper

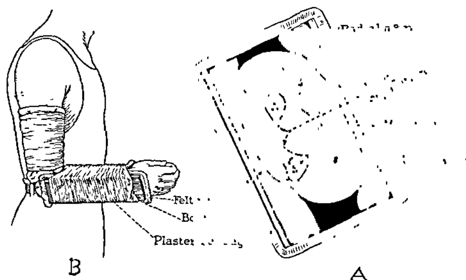


Fig. 7.—Immobilization for radius and ulna. A, Cross-section; B, forearm immobilized.

and lower fragments of the radius and rotate them into normal relation before they are fixed, and while this is being done a decision should be made as to the amount of pronation or supination that is best to maintain in the cast when it is applied. If this is done, too great torsion will be avoided.

The method of fixation to be used is usually a problem. If possible, a long onlay bone graft should be used, wedged at each end, as in Fig. 2, B, so it will form part of the host bone and be wedged into it. If this cannot be done, a long plate with at least three screws on each side of the fracture can be used, with an osteoperiosteal graft put around the site of fracture, well above and well below. When a substantial onlay graft is put in both radius and ulna there may be

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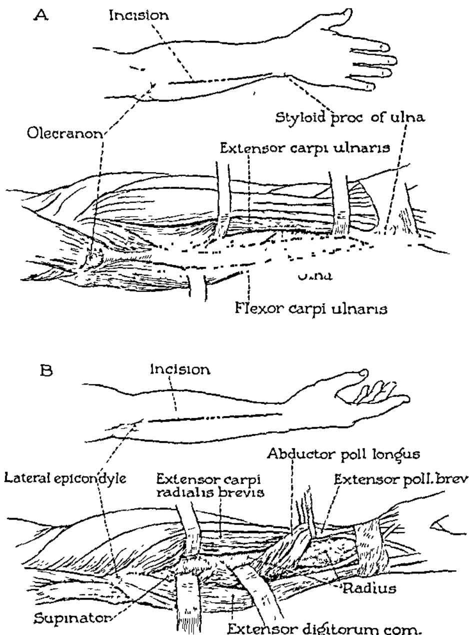


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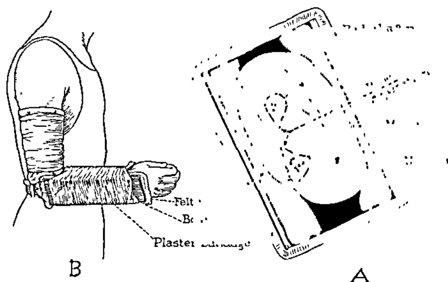


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some difficulty in closing the wound after operation. These grafts should be applied, not on the side of the bone nearest the surgeon, but so they will lie under the muscles and not between the bone and the skin. Inasmuch as both radius and ulna are somewhat irregular in shape (Fig. 7, A) a bed will have to be carefully prepared and a graft set in on a good, flat surface on each bone. The circumference of these bones is small and, if a bed is not made for them the contact between the graft and the host bone is very slight.

Immobilization

It is of advantage to immobilize these fractures with a board splint, well padded with felt ½ inch (1.3 cm.) thick, applied to the anterior and posterior surfaces and extending from the elbow to the wrist. The splint extends beyond the forearm on both the radial and ulnar sides and puts firm pressure on the anterior and posterior surfaces, forcing the muscles between the bones and still allowing adequate circulation and preventing constriction of the forearm (Fig. 7, B). These splints can be applied very snugly. The splint and arm are then encased in plaster from the base of the forearm to the axilla, with the elbow at a right angle and the forearm in the position of greatest relaxation of the rotating muscles. This may be in supination, midpronation, or pronation. The optimal degree of rotation without strain should be determined at the time of operation.

The arm is carried in a sling which extends from the base of the fingers to the axilla. *The fingers never should be included in the immobilization dressing.* The patient should be encouraged to flex and extend the fingers, not just to wiggle them, from the first day after operation.

Time of Healing

Fractures of the forearm do not heal readily after long nonunion, and immobilization is necessary for a considerable period, three to nine months being not unusual. Frequent inspection is not advisable. Motion of the hand and fingers, however, is advisable and, if the patient has been properly prepared prior to operation, the fingers should be functioning while the arm is immobilized. Physical therapy cannot be instituted in these cases. Motion of the elbow cannot be allowed. Roentgenograms at intervals of six weeks are sufficient to determine the progress of formation of callus but it may be necessary to take roentgenograms at more frequent intervals for the first few months in order to determine that the fragments are not changing position. Bowing can occur in spite of what seems to be adequate

external immobilization. It may be necessary to give the ulna support on its inferior surface, extending from the elbow to the base of the fingers. Frequently this support is given *at the time the stitches are*

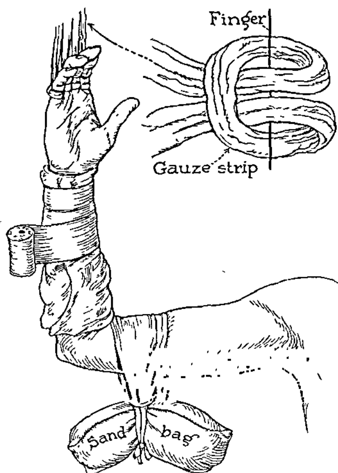


Fig. 8.—Method of suspending the member when stitches are removed and first dressing is applied after operation on bones of the forearm.

removed and the second dressing is applied. This can be done without disturbing the fracture, if the hand is suspended as is shown in Fig. 8.

CARPAL NAVICULAR (SCAPHOID)

Fracture of this bone may exist ununited for some time before it is discovered, and frequently it is passed off as a sprain of the wrist. When the surgeon is consulted, the fracture is found by an oblique roentgenologic view, with the dorsal surface of the radius downward, resting on the plate, and the hand in an oblique position.

These fractures are treated in either of two ways:

1. If traumatic arthritis already has been set up and there is considerable absorption of bone on each side of the site of fracture, removal of the scaphoid should be considered. In this case, incision is made dorsally and maybe transversely and, with the tendons retracted, the scaphoid is exposed but is not so easily identified or removed. The joint margins should be found with the point of the scalpel and the posterior ligamentous structures should be severed, so that the bone can be plainly outlined. The fragments usually are removed one at a time, or the bone is taken out in small pieces.
2. If there is no traumatic arthritis, a splinter graft may be inserted into a drill hole which extends through the middle of the bone longitudinally, the splinter being driven across the two fragments. The entry for the drill hole is made through the "snuff-box."

Incision

Incision is made just below the lower end of the radius, extending toward the thumb in what is called the snuff-box. The drill is inserted in the long axis of the bone.

Immobilization

Immobilization should be made with the wrist in partial extension and the thumb in full extension and abduction. If the graft is successful, six to eight weeks serve to establish union, after which time motion may be instituted.

METACARPALS

An ununited fracture of the metacarpals is usually complicated by much scar tissue in the hand and this must be removed and replaced by healthy skin before surgical operation should be attempted. These are short bones, closely held by the interosseous muscles and the lumbricals, and it is impossible to pry them back into position without somewhat shortening them and squaring off the ends of the fragments. Deformity or nonunion of these bones can disable the hand out of all proportion to the apparent seriousness of the injury. The deformity should be corrected completely. The ends of the fragments, and the shaft as far above and below the fracture as is possible, should be freed, and the ends then squared off and fastened with a small steel plate (Fig. 9).

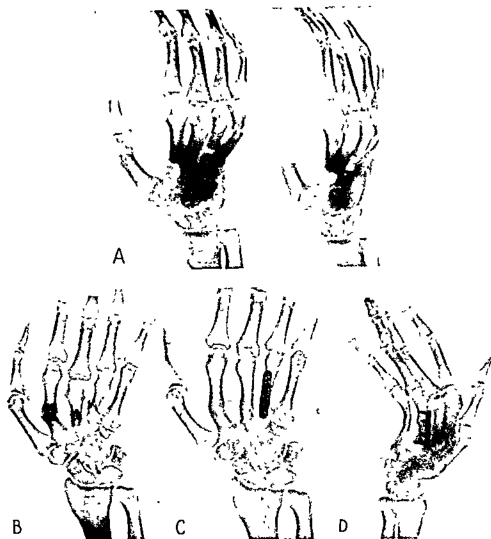


Fig. 9.—Fracture of the metacarpals. A, The injury, oblique view; B, the injury, anteroposterior view; C, repair, anteroposterior view; D, repair, oblique view.

Immobilization

Immobilization should be effected by a straight edge splint posteriorly, held firmly at both ends and with a pad over the point of fracture. The deformity always recurs as a posterior angulation because of the direction of pull of the interossei. If the ends of the fragments are well abutted and firmly held, union should occur in from six to ten weeks.

THE FEMORAL NECK

The repair of ununited fracture of the neck of the femur contemplates reestablishment of the weight bearing line of the shaft of the femur, directly up into the acetabulum (Fig. 10). Whether or not

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be taken out piecemeal, but this should be done thoroughly before the bone work is started. There need be no fear of the capsule not reforming after a successful operation and, if the fibrous tissue and the capsule are not removed entirely, the operation probably will not be successful.

Inspection of Femoral Head

After removal of the capsule and the fibrous tissue lying between the head and the shaft, the surgeon is able to inspect the head by rotating the shaft outward and abducting the leg. The fibrous union between the head and neck is severed (Fig. 11, C). The head should then be thoroughly cleared of all fibrous tissue and the surface freshened. The head must be freely movable in all directions, and every vestige of adhesion must be removed. If the surface of the head bleeds at any point it is not removed. Even though the roentgenogram indicates that there has been condensation of bone and the head appears to be dead, if the bone seems of good quality and capable of bearing weight the results are much better when the head is not removed. Phemister and Magnuson have both shown, from specimens obtained at necropsy, that there is creeping substitution and reestablishment of circulation from the shaft to the head when the shaft is properly and firmly fitted into the head and weight bearing is allowed.[1]

Repair by Brackett-Magnuson Operation

The ideal to be attained in the repair of any fracture is to restore the parts to normal weight bearing. An operation which allows direct weight bearing between the shaft and the acetabulum, with the head held between these two structures, most nearly approaches this ideal. It is not always possible to do this, but where it can be done it is the operation of choice.

It is assumed that the head and the upper end of the shaft have been exposed and thoroughly cleared of fibrous tissue and capsule. The next step is to remove the trochanter in such a way that its muscle attachments remain. A broad chisel should be used for this (Fig. 11, D). One corner of the cutting edge of the chisel should be placed at the base of the neck, the cutting edge sloping at an angle from the front of the trochanter, backward and medialward, and the handle of the chisel pointing downward and outward. By this means the posterior lip and outer part of the trochanter can be taken off completely, leaving the beveled upper end of the shaft with a cut surface sloping downward and outward, facing somewhat

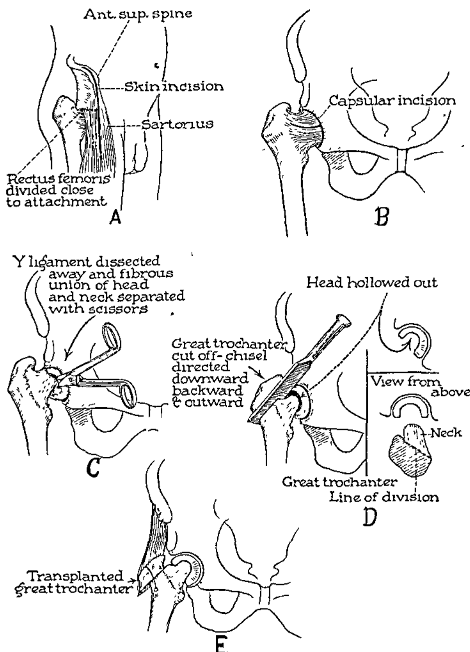


Fig. 11.—Stages of Brackett-Magnuson operation. A, Relation of incision over femoral neck to the underlying structures; B, incision in capsule of hip joint; C, separation of head from shaft of femur; D, removal of trochanter and detail of adaptation of head to remnant of neck; E, relation of lower fragment to head of femur and the change in position of the trochanter.

around the acetabulum and at its distal attachment (Fig. 11, B). The incision is continued as far as possible posteriorly on both superior and inferior surfaces. The capsule probably will have to

following operation. The patient is encouraged to use this leg regularly, moving it in all directions and exercising the ankle, the knee and the hip freely. The front is used on the well leg only when the patient is turned into the prone position, which is done twice daily for nursing care.

After the stitches are removed from the injured leg, the cast is taken off twice a day and the ankle and knee are exercised gently *in active motion or assisted motion.* The hip is flexed and extended and gently rotated internally, with the leg always held in abduction.



Fig. 12.—Abduction fixation used after operation for ununited fracture of the neck of the femur. Wood strip should be incorporated after the plaster is hard enough that it will not dent where the plaster rests on the wood. Spica should hold the upper end of the femur upward and inward.

The patient is permitted to sit up, and is encouraged to do so, as this establishes flexion in both hips. On a hospital bed he can be raised a little higher each day into a sitting position.

This treatment extends over a period of eight weeks, at the end of which time the patient is stood on his feet, supported by the elbow on each side, and is encouraged to walk. There need be no fear about the hip slipping out if the shaft has been properly placed in the head. Weight bearing pushes the shaft further into the head and weight bearing may be started before union has occurred, but not until the trochanter has united to the shaft. The patient may have

backward. When the trochanter and its attached muscles are freed it will be found that the upper end of the shaft of the femur can be handled with considerable ease and placed in any position in relation to the acetabulum. When this is done the shaft can be pried further outward and good exposure made of the head. The head is then hollowed out with a motor-driven bur to simulate a parabola, not a hemisphere (Fig. 11, D and E). The top of the parabola should be aimed at the upper, inner surface of the head. When this excavation is complete the upper end of the shaft should be patterned to fit the excavation. Then, with a Murphy skid lifting at the edge of the acetabulum and, if possible, at the upper edge of the cut surface of the head, the upper end of the shaft is pried inward and downward and then is allowed to slip up into the head as the leg is abducted. If the leg is abducted to 45 degrees and the head and shaft are held firmly together, the head should move freely in every direction as the shaft moves, without other fixation than good bony contact.

If there is enough overhang on the outer margin of the head, a small bone or ivory nail can be driven through the outer edge of the head and down into the solid part of the shaft, further to stabilize the head on the lower fragment. If the lower fragment has a tendency to prise out of the head when the leg is brought into adduction, some obstruction should be looked for and removed. It is important to have free motion of the head in the acetabulum as the shaft is moved. When this has been accomplished the trochanter is pulled downward, by wire or silk suture, to a place below, and is thus returned to its former site with relation to the muscles, the lower end of the trochanter projecting into the muscles when the leg is in abduction (Fig. 11, E). The trochanter is secured by a suture through a hole drilled in the cortical bone of the shaft and passing over the trochanter into the muscle attachment. If malleable iron wire is used, the trochanter can be pulled down and held in position much more securely than if the suture were put through the trochanter itself, which is usually too soft to withstand much pressure, whereas the tendinous attachments will stand great pressure without cutting.

The legs are placed in abducted position and a cast is applied to both legs below the knee; abduction is maintained by a bar of wood, 1 by 2 inches (2.5 by 5 cm.) respectively in thickness and width, placed between the legs, preferably about two-thirds of the way down the shaft. In Fig. 12 this strip of wood is placed not far above the ankles.

After-Treatment.—The casts are cut longitudinally and, on the unaffected leg, the front of the cast is removed on the third day

roentgenogram it may appear that the shaft is about to slip off the rim or out of the acetabulum, but it must be remembered that the bone at the upper end of the shaft, bordering on the trochanter, is cancellous and does not cast a hard shadow. In some cases, from the roentgenologic evidence, one would say there was little or no weight bearing between the end of the shaft and the acetabulum, yet the patient is walking comfortably and well, and has been doing so for a long period of time (Fig. 13).

This operation does not give as free motion or as stable weight bearing as the one previously described, because of lack of bearing surface, but it does give a good functioning hip when properly performed and, when it is necessary to remove the head, it is the operation of choice.

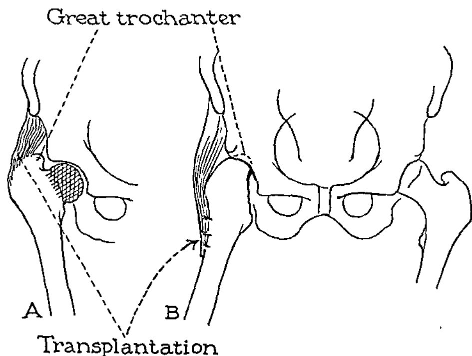


Fig. 14.—Colonna operation for ununited fracture of the neck of the femur. A, Muscles attached to trochanter in normal position; B, muscles attached lower on the femur, femoral head removed, and upper end of trochanter in acetabulum.

Colonna Operation

The Colonna operation contemplates placing the upper end of the trochanter in the acetabulum, removing the muscle attachments from the trochanter, but not displacing the trochanter downward. It gives a less stable result than either of the two operations just described. Some surgeons find it impossible to keep the upper end of the trochanter in the acetabulum without removing the posterior lip entirely (Fig. 14).

some difficulty in bringing the leg into adduction, and may want to bend the knee on the unaffected side in order to compensate for the apparent shortening. This should not be permitted. There is not more than ¾ inch (2 cm.) of shortening and the pelvis should tilt down on this side to compensate for the shortening. The shoe should not be built up, because tilting of the pelvis helps force the shaft in a direct line toward the acetabulum and maintains some abduction on that side as compared with adduction on the opposite side.

Whitman Operation

The Whitman operation contemplates the same mechanics, with removal of the head. It is the operation of choice when the head of the femur is beyond redemption and incapable of bearing weight.

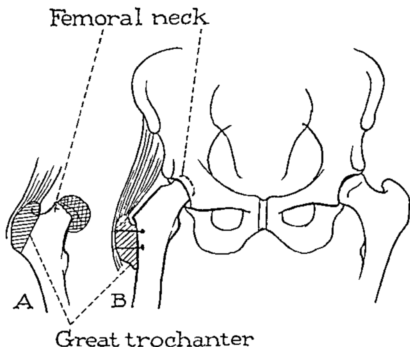


Fig. 13.—Whitman operation for ununited fracture of the neck of the femur. A, Trochanter in normal position; B, trochanter moved to new position, femoral head removed, and remnant of neck in acetabulum.

Experience has taught that placing the upper end of the shaft too deep in the acetabulum, when the head has been removed, does not allow as satisfactory motion as when the upper end of the shaft is permitted to rest on the outer third of the acetabulum. The upper end of the shaft can be maintained in this position if the trochanter is removed exactly as has been described in outlining the previous procedure, and if the trochanter is fastened well downward and outward on the shaft, after the upper end of the shaft has been placed in the desired position on the outer third of the acetabulum. In the

Nailing

The use of the many types of nails or other form of metal fixation presents the same disadvantage as a bone graft. There have been reports of successful nailing in cases of fracture in which the fragments have been held in good position, but in a case in which the fragments have been ununited for some time a graft would be preferable to a metal support because of the possibility of regeneration of part of the neck.

Osteotomy

In cases of questionable union, wherein the position of the fragments is satisfactory and the head is in good condition, high osteotomy which throws the injured leg into abduction, thereby changing the angle at which the weight strikes the ilium and acetabulum and head, sometimes results in satisfactory function (Fig. 15).

Care after Bone Graft, or Use of Metal Nail, or Osteotomy

Following operation for bone graft, insertion of a metal nail, or osteotomy, fixation in a cast must be maintained for sufficient time to allow bony union to occur. This would vary from three to nine months, although union usually takes place in about two months after osteotomy. Even with osteotomy, however, mobility cannot be permitted in the hip for at least eight weeks. With metal or bone graft fixation, a full abduction cast, in which is included the body and the affected leg, or both legs, must be maintained for from three to nine months, and even then there is a meager chance of sufficient formation of bone

THE FEMUR

The femur is controlled by the strongest group of long muscles of any of the long bones and the angle of pull of these muscles must be taken into consideration whenever either internal or external fixation apparatus is applied. The deformities caused by the pull of these muscles repeat themselves in the various locations of fracture time after time. The adductors, the largest single group, pull at an angle directed between the internal condyle and the symphysis; consequently the angulation of the femur is almost always lateralward. In the upper third, the external rotators rotate the upper fragment outward and the flexors of the thigh flex the upper fragment; the iliopsoas flexes and externally rotates it. In the middle of the shaft the deformity usually recurs in the shape of a lateral bowing. In cases of supracondylar fracture the lower fragment is usually flexed, the lower fragment being displaced backward on the upper fragment by the gastrocnemius, and the quadriceps and biceps mus-

Bone Graft Operation

In this location, bone graft operations require many months of convalescence, with uncertain results so far as union is concerned. When a fracture has become ununited there is much scar tissue lying between the head and the shaft. The shaft is usually displaced upward, and bony contact cannot be brought about until the fibrous tissue is removed and the lower fragment is brought into something like normal position. If a bone graft must pass through this fibrous

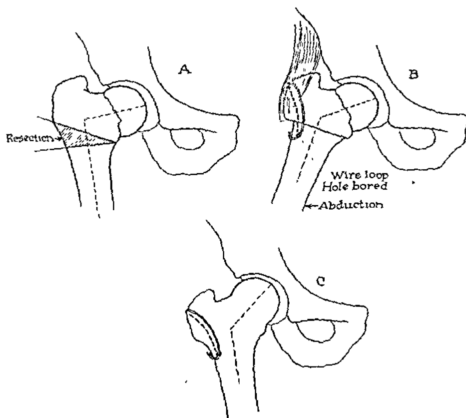


Fig. 15.—Osteotomy for ununited fracture of the neck of the femur. A, The resection; also, improper 90-degree angle between shaft and neck; B, apposition, with femur in abduction; C, proper new angle between shaft and neck.

tissue, which is poorly supplied with blood, there is small chance of a weight-bearing structure developing.

If there is good position of the fragments, with comparatively little absorption of the femoral neck, it might be advisable in some cases to place a very heavy bone graft from well below the trochanter up into the head, if the head is of such quality as to give it support. The head, however, is extremely shallow in most cases, and the upper end of the graft would have insufficient support.

tion and suspension are necessary in treatment of fracture of the shaft of any part of the femur.

In a supracondylar fracture with deformity, the knee should be put into a position of flexion of a degree sufficient to remove the pull of the gastrocnemius muscle; this may be 90 degrees or more. The Kirschner wire or Steinmann pin should be put through just below the knee, in the tibia, through good hard bone and then, in order to prevent straightening of the knee, the foot should be weighted and held close to the bed with the knee in flexion, or the lower end of the splint should be held down to the bed by some other means. The best method of suspension with traction is by a combination of the Thomas splint and Pearson attachment (Fig. 16). This will allow for motion of the knee during the period of healing.

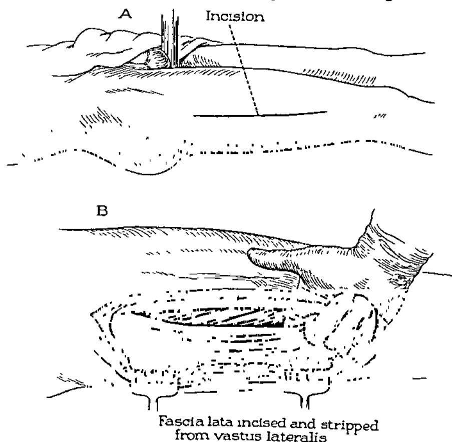


Fig 17.—Incision to approach femur. A, Through skin; B, through fascia lata, which is separated from the muscle

Incision

The best approach to the femur is through the lateral surface; never through the middle of the quadriceps. Incision through the skin should be almost the full length of the thigh, parallel to the bone

cles cause overriding of the lower end of the upper fragment anterior to the condyles.

These deformities are fairly standard, and once they occur the group of muscles causing the deformity is contracted. Therefore, in any attempt to reduce the deformity, the muscles which cause it must be stretched. Fortunately the femur is usually of such diameter and strength that if the ends of the fragments are squared off so they can be abutted, they can be used as a fulcrum on which to stretch the contracted muscles. Sometimes as much as 3½ or 4 inches (9 or 10 cm.) of shortening may be overcome. When this is done, however, it must be remembered that the muscles still exert tension and

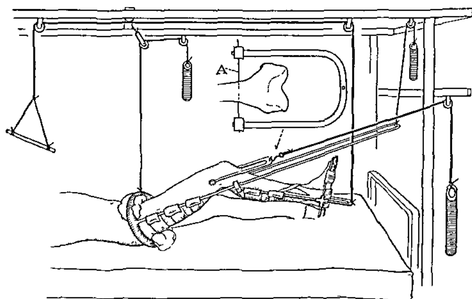


Fig. 16—Thomas splint and Pearson attachment used for fracture of shaft of femur. A, The Kirschner wire through the femur.

strong pull at the site of fracture and, unless the fixation apparatus is extremely strong and its fixation in the bone unusually solid, it will be bent or broken in spite of its apparent immobility. Therefore, when any deformity of the femur is reduced and the fracture is repaired, means must be provided to counteract the pull of the muscles by counterbalanced weight which will remove strain from the site of fracture. This can best be done with a Kirschner wire inserted through the lower part of the shaft of the femur, not through the cancellous bone just above the condyles. The Kirschner wire should have attached to it enough weight to withstand the contracture of the muscles of the thigh, usually about 15 to 25 pounds (about 7 to 11 kg.) depending on the size and strength of the muscles. Trac-

about 2 inches (5 cm.) anterior to the posterior margin of the vastus lateralis (Fig. 17, A). *The lower edge of the skin is retracted* and the fascia is split about ½ to 1 inch (about 1.3 to 2.5 cm.) posterior to the skin incision. The posterior part of the fascia is separated from the muscle by smooth, blunt dissection (Fig. 17, B). The posterior, rolled edge of the vastus lateralis is raised forward (Fig. 18) and

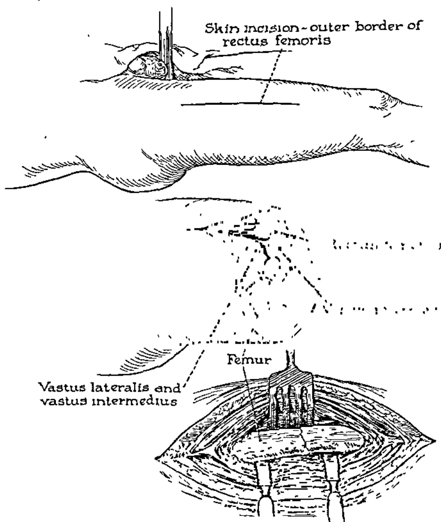


Fig. 20.—A somewhat anterior approach to the femur.

held with retractors, while the posterior elevator is pushed through the attachment of the muscles to the bone, separating the muscles from the bone (Fig. 19). The muscles above and below the fracture can be separated easily as a rule and a curved, periosteal elevator with a long handle can be slipped over the anterior circumference of the bone and pulled medially, following around the medial surface of the bone; these two periosteal elevators will act as retractors

Outer vasti muscles

Fig. 18.—Isolating posterior rolled edge of vastus lateralis prior to retraction.

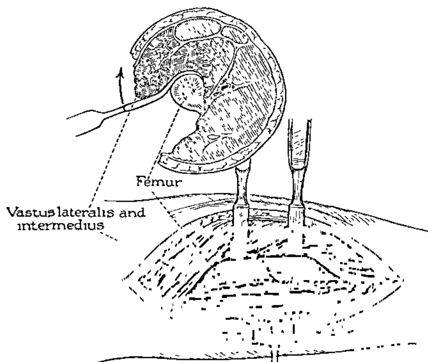


Fig 19.—Separating the muscles from the femur.

or not operation is required in the case. As mentioned before, the Thomas splint with Pearson attachment properly applied is the most satisfactory means of accomplishing the desired result.

Length of Time of Immobilization

This will depend on the rapidity of formation of callus, but six months to a year is not an undue time to wait for strong union. It may be that a walking caliper properly applied can be used, if there is sufficient callus to maintain the fragments in position. This should be carefully fitted and it must be provided that little or no weight is borne on the extremity until the callus is of sufficient strength to accept the weight of the patient.

THE TIBIA

The tibia is the most easily approached of any of the long bones. In repair of ununited fractures, the incision should never be made immediately over the bone. In the case of a compound fracture in which there is cicatrization over the anterior surface of the tibia, long preparation may be necessary before any surgical procedure should be attempted on the bone itself. There should be good, viable skin covering the entire anterior surface before a method of repair is attempted.

Not infrequently there is a defect in the tibia and nonunion of the fibula. In such cases the fibula should be cut and, if necessary, a piece should be excised before any attempt is made to adjust the fragments of the tibia. The excised portion may be used as a graft or auxiliary support for the tibia. If there has been any loss of bone substance it is inadvisable to try to fill in a space between the upper and lower fragments of an ununited tibia by inserting a graft or two grafts because, even if they do unite, the bone is not of sufficient strength to allow full weight bearing without considerable hazard of a second fracture. Therefore, it is wise to bring the ends of the fragments together as closely as possible at the expense of length of the lower leg. If the defect is so great that the leg would be shortened to a degree that would interfere with function, amputation should be seriously considered. In cases of long-standing nonunion the ankle and foot are often rigid, the ligaments are atrophied, and many months are required to restore this part of the weight bearing mechanism to comfortable function. Further, the circulation is poor in the lower half of the tibia and union occurs slowly at best. In addition, there is likely to be marked swelling and edema which, while they should be overcome before operation is attempted, will recur after operation. Under such circumstances a properly fitted artificial leg is

to open the wound wide. The scar tissue should be removed completely by sharp dissection around the site of fracture and from the ends of the fragments, which should be completely freed. The retraction exerted by the strongly held periosteal elevators will suffice to aid in causing angulation of the fragments toward the surgeon.

If, because of the density of scar tissue or other complications, this incision is not convenient, an incision can be made farther anterior, between the rectus femoris and vastus lateralis muscles, and the femur can be approached from this angle (Fig. 20).

Operation

When all scar tissue has been removed, the ends of the bones are prepared for proper abutment. They must be squared so that strong pressure will be exerted against each when they are angled back into the wound. Resection of the ends will cause some shortening, but this can be compensated for by a lift on the shoe after the fracture has healed. Not only angulation but rotation must be corrected. The upper fragment should be rotated with a Lane forceps to determine in which degree of rotation it is most relaxed, and the lower fragment should be brought into the same rotation. Otherwise a twist will be present at the site of fracture. When the squared ends are brought into satisfactory abutment, and the deformity has been corrected, the fragments can be held by an inlay bone graft (Fig. 2, C), an inlay medullary combination graft, or a plate plus a graft. Whichever method is selected, the fixation apparatus must be of large enough size and great enough strength to withstand the pull of the muscles, which work twenty-four hours a day and must be counterbalanced or the internal fixation surely will give way.

Immobilization

Casts never should be used with the expectation of immobilization. The contracture of the muscles controlling the femur will cause angulation of the fragments within a cast, because the hip and pelvis cannot be entirely fixed. The muscles are of such bulk that they act as a pillow around the bone and firm immobilization cannot be secured through this soft mass. Even if the cast could be placed tightly around the thigh, which is almost an impossibility, the fragments would undergo angulation by pressure on the muscles of the lateral surface of the thigh and atrophy would result from pressure between the angulated bone and the cast. The fragments sometimes have been pushed clear through, so that their ends could be felt under the skin. Traction and suspension should be applied, whether

flat, anterior surface. The bone in this location will regenerate, whereas if the crest is removed the bone is weakened and does not regenerate as does the cortex of the shaft not involving the crest (Fig. 21).

The fragments should be freed completely of scar tissue after the muscles are separated, and should be exposed along the lateral surface of the bone. Any graft or plate used should be fastened to the lateral surface, not to the anterior surface, of the bone. In this lateral location the graft receives a much better blood supply and is covered by muscles so that an uneven surface will not lie immediately under the skin.

An inlay bone graft or combination inlay medullary bone graft is usually the method of choice (Fig. 21, B). It is possible to make an inlay bone graft on the lateral surface and another on the anterior surface without damage, and this of course gives a very strong form of union. A Martin bandage should be used around the thigh for a tourniquet; this not only facilitates the work but saves tremendous loss of blood.

Frequently it is desirable to expose the tibia so that a graft can be removed from it (Fig. 21, C).

Immobilization

Immobilization can be best made with a circular cast extending from the midthigh to the ends of the toes, with the foot at a right angle, the cast extending beyond the end of the great toe on the plantar surface of the foot and cut back to the ball of the foot on the dorsal surface. When the cast is changed, great care must be exercised in handling the member. Elevation of the leg by the heel or toes, without support of the fracture and of the leg above the fracture, should not be permitted. It is best to use some form of mechanical support rather than depend on assistants. A piece of muslin torn in strips and hung from a horizontal bar above the leg gives smooth support to the under surface, above and below the fracture; it will aid materially in ease of reapplication of the cast and will prevent motion during the procedure (Fig. 22, A and B).

Length of Time of Immobilization

Fractures of the tibia heal slowly. If union is secured in from four to twelve months the result can be considered satisfactory. If the fragments are well abutted end to end, a walking caliper can be applied as soon as formation of callus has started, as the cast supporting the caliper gives smooth circular support and is applied directly to the skin.

much more comfortable and much more satisfactory, as far as function is concerned, than is an extremely short or weak bone.

Incision

The incision should be made lateral to the crest of the tibia, with the ends curved medially to about the midline of the shaft on the anteromedial surface (Fig. 21, A). In this way the flap can be re-

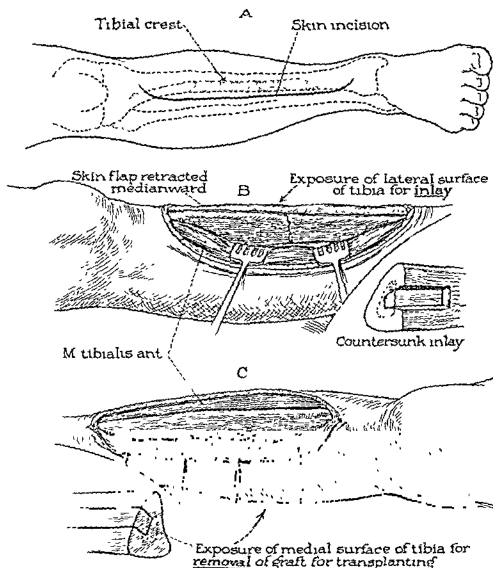


Fig. 21.—A, Incision for approach to tibia; B, exposure of fractured tibia; C, exposure of uninjured tibia for removal of a graft.

tracted and the suture line will not occur immediately over the bone. The same type of incision should be used when removing a graft, which should never be taken from the crest of the tibia but from the

SECTION II

INJURIES OF THE SPINAL COLUMN

Arthur G. Davis, M.D.

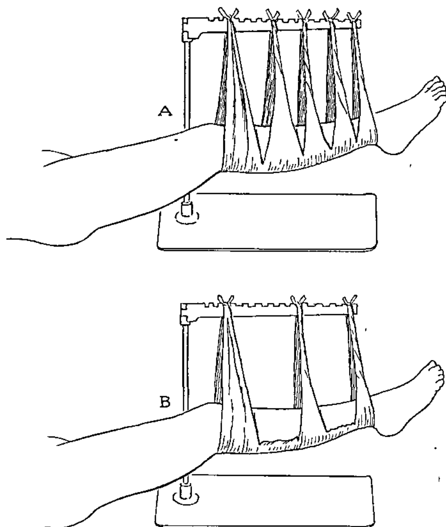


Fig. 22.—Muslin support of leg to aid in application of cast. A, Five supports; B, two supports cut away.

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CHAPTER VI

GENERALITIES AND CLASSIFICATION

GENERALITIES

CERTAIN generalities bearing on spinal injury have become apparent since the inception of actual reductions fifteen years ago. Notwithstanding the ever-present necessity of planning treatment on the individual merits of the case at hand, the following general observations seem important:

1. The centrum of a vertebra forms callus as rapidly as any other osseous structure.
2. The intact posterior arches of vertebrae when hyperextended are capable of sustaining the imposed weight of the torso without the aid of the centrum.
3. Hyperextension with notable exceptions is as important in the reduction of spinal fractures as is straight-line traction in long bones.
4. The tensile strength of the anterior longitudinal ligament is such that a wide margin of safety protects the patient against damage by hyperextension. (See page 104, footnote.)
5. The anterior longitudinal ligament when interpreted correctly acts as the main reducing medium as well as the main check strap to excessive hyperextension.
6. Roentgenography of the posterior arch cannot be depended on to reveal most fractures and dislocations of this portion. Roentgenograms of the posterior arch are frequently found to be a deception and an illusion.
7. Because of the impossibility of roentgenographic exposure of the posterior arch, the factor of horizontal traction during reduction is important as a protection to the posterior arch.
8. Because the status of the posterior arch is unknown, ambulatory treatment is not permitted for six weeks, since the

4. Cervical
   (*a*) Third to seventh
   (*b*) First and second

Special Groups

1. Spinous processes
2. Transverse processes
3. Articular processes
4. Laminae
5. Hyperextension fractures
6. Unilateral compression fractures

Dislocations

1. Cervical—unilateral and bilateral
2. Luxations
   (*a*) Cervical
   (*b*) Posterior dislocation, fifth lumbar

posterior arch takes all the compression strain in hyperextension. There is no general agreement as to duration of convalescence in recumbency and with protected weight bearing. It is the author's opinion that, with a well-hyperextended spinal column, protected by a plaster jacket of the three point pressure type (see Fig. 29), it is important for patients to be ambulatory on the average at six weeks for the purpose of inducing strong structural callus. The author believes that no advantage accrues to the patient by remaining recumbent beyond this period but, on the contrary, that general diffuse atrophy of bone and muscle must occur as a result of further recumbency. Others, however, are inclined to consider three months of recumbency the minimal period consistent with sound callus formation and safe weight bearing, even when the patient is protected in a hyperextension jacket.

9. Barring the individual demands in exceptional cases, ambulatory treatment in guaranteed hyperextension at six weeks is important to induce weight bearing callus in the centrum.
10. *It must be assumed that the damage to the vertebra is* greater, sometimes much greater, than the first roentgenograms indicate. The immediate spontaneous reaction to hyperflexion is an immediate recoil in extension. In other words, a certain amount of spontaneous reduction frequently takes place in the interval between the moment of injury and the first roentgenography.
11. Visualizing a very definite sequence of steps, including apparatus, reduction, adequate fixation, return to function and final resumption of former occupation, helps to define the detail and criteria of treatment essential to perfection of the result.

The following aims to divide the classes of spinal injuries ordinarily encountered and outlines sequences for the various classes.

CLASSIFICATION OF SPINAL FRACTURES AND DISLOCATIONS

Compression Fracture Type

1. Thoracolumbar—Tenth thoracic to fifth lumbar
2. Midthoracic—Fourth to ninth
3. Upper thoracic—First to fourth

CHAPTER VII

COMPRESSION FRACTURES

UNCOMPLICATED CRUSH FRACTURE FROM TENTH THORACIC TO FIFTH LUMBAR VERTEBRA

THIS region of the spinal column, the lower thoracic and entire lumbar region, is more susceptible to fracture than all other parts. Statistical data reveal that 75 per cent of all spinal fractures occur within these limits. A number of technics besides the one to be described are eligible, those of Rogers, Dunlop and Jones being the most outstanding. The foot suspension technic has proved most effective as measured by ease of operation, degree of reduction and protection of the posterior arch and comfort of the patient.

First Aid

1. Specialized care starts at the site of injury. Fig. 23 and Fig. 24 depict dangerous handling; Fig. 25, proper handling.

2. All transfers in the hospital are also guarded. Correct handling is illustrated in Fig. 26. When the patient is rolled onto the back, a pillow is first placed on the bed or stretcher opposite the fractured vertebra; the patient is rolled from prone to supine with the pillow under the fractured region.

3. Neurologic examination should precede all others. Such examination should include elicitation of patellar reflexes, heel cord reflexes, and the Babinski reflex; investigation of cutaneous sensation covering the areas of the peripheral nerves; and testing of the following voluntary motions: dorsiflexion, plantar flexion, inversion and eversion of the foot, and flexion and extension of the knee. If massive paralysis is present, the whole lower extremity should be lifted from the bed and allowed to drop. If an effort is made on the part of the patient, however feeble, to arrest the drop, continuity must be assumed. Strong pressure posteriorly on the big toe, with the interphalangeal joints flexed, elicits pain and an effort to withdraw the extremity is exhibited by muscle contraction somewhere from the groin down. This also suggests continuity.



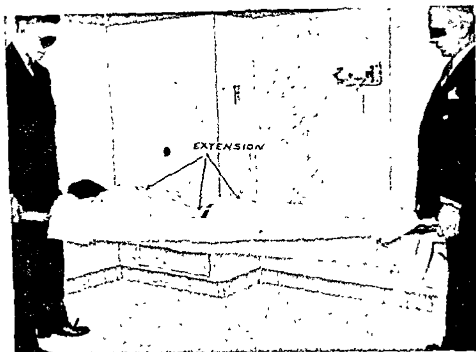


Fig. 25.—Correct first aid. Prone position uses anterior longitudinal ligament as check strap; tends to reduce compression by tensing anterior ligament.

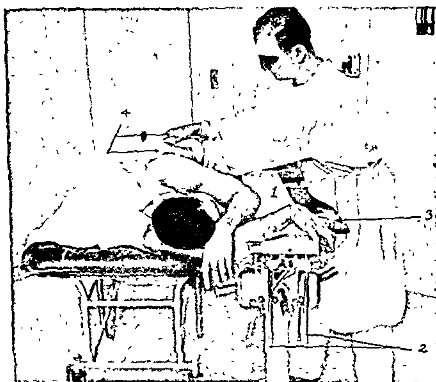


Fig 26.—Method of handling in hospital. Rolling the patient. *1*, Canvas hammock in place; *2*, adjustable rack to raise hammock; *3*, table leaves in place; *4*, one hand on shoulder, one on buttocks prevent rotation at point of fracture.

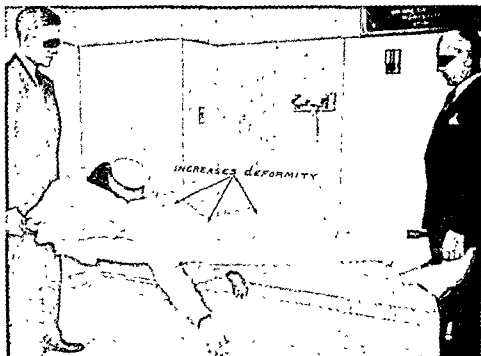


Fig. 23.—Damaging first aid. Ordinary attitude in recumbency increases angulation.

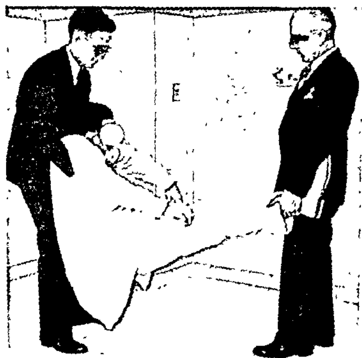


Fig 24.—Damaging type of carry This opens dislocations and increases compression fractures, has caused paralysis.

5. Without anesthesia and usually without opiates, the patient is then asked to hold himself from sliding by hanging on to the end of the table. The table leaves are lowered away.

6. The feet are then simply elevated. The suspension operation occupies but a few seconds. The free end of line is secured. If the thoracolumbar angle is not sufficiently hyperextended, the hammock is then slackened away.

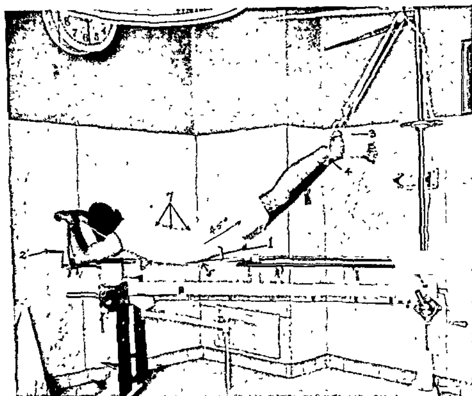


Fig. 28—Typical reduction of uncomplicated thoracolumbar crush fracture *1*, Ample clearance between anterior spines and hammock affords index of adequate hyperextension; *2*, hammock can be lowered with crank to increase further the hyperextension; *3*, sheet wadding cushions holder; *4*, holder loop of canvas with ring to suspend, *5*, canvas hammock; *6*, weight of chest carried by hammock; *7*, maximal hyperextension obtained at region involved.

7. The position is then scrutinized. The criteria of correct position are as follows:

(a) Note that the suspension point is fully 12 inches (30.5 cm.) distal to the ankle slings. This insures the factor of horizontal traction so essential to protection of the posterior arch.

(b) Note the angle of inclination of the lower extremities; 45 degrees is found to be ideal. Less elevation exerts too little traction on the anterior common ligament. More elevation may dangerously

If the spinal cord or cauda equina has been severed or so badly contused as to entail destruction, signs are negative and a careful consideration of roentgenograms and of the general status of the patient will determine if immediate measures should be applied or treatment postponed. Since it is impossible to decide from the signs whether or not irreparable damage has been done, the question of immediate reduction by hyperextension should be considered for the reason that, if pressure exists, it is important to decompress.

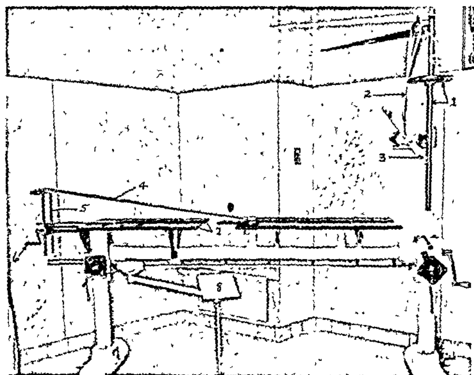


Fig. 27.—Equipment for treatment of uncomplicated thoracolumbar compression fractures. *1*, Geared telescoping mast permits quick adjustment of suspension, 2 and 3, block and tackle with spreader; by adjusting mast to maximal height, opening block and fall to table level, then using free end of line, the feet are suspended in a few seconds and the free end fastened to the crossbar; *4* and *5*, hammock and rack adjusted to clear understructure; *6*, canvas hammock is made slack or tense by means of crank, *7*, table top is dropped for application of jacket, *8*, cassette holder adjustable to vertical plane for roentgenogram.

4. Highly efficient equipment, ready for reduction, is shown in Fig. 27. Several types of commercial fracture tables embodying the mechanics essential to suspension of the feet are available. Apparatus consisting of an adjustable hammock, a mast or other overhead fastening device and block and tackle can be improvised. Note in Fig. 28 that the telescoping mast has been raised to full height.

rim. If this detail is thought out in advance, no difficulty is experienced. The plaster jacket must reach from the sternal notch above to the pubic rim below, posteriorly merely from the lower angle of the scapulae to the gluteal fold.

9. Fifteen to twenty minutes is allowed for the plaster to dry. The hammock is raised if necessary to permit replacement of the table top. After the leaves are in place, the stretcher is brought alongside, the hammock is slackened away and, resting his chest on the table, the patient is then rolled onto a pillow or shifted in the prone position. Meanwhile, the tackle lowers the legs.

10. The day following the reduction, a check roentgenogram determines the degree of reduction. If restoration of vertical height is insufficient, as measured by calipered comparison with the centrum above and below the involved one, another manipulation should be considered immediately. Re-examination of the original roentgenogram with those following the manipulation should be made to determine if obstruction to reduction can be detected (see Fig. 55).

If not, manipulation should be repeated, using foot suspension combined with a forward thrust at the level of the involved vertebra, but not directly against the posterior arch. This time, with the feet fully suspended and with more hyperextension than before, a forward thrust is made with the thumbs, 2 inches (5 cm.) lateral to the midline.

Very rarely is it necessary to manipulate again. The foot suspension method, using only gravity with the factors of horizontal traction and hyperextension leverage as described, may be expected to reduce completely uncomplicated crush fractures of the thoracolumbar region.

When the plaster has dried, the table leaves are lifted in place and canvas lengths are slacked off. Meantime, an assistant operates the block and tackle, exerting more traction if necessary to maintain hyperextension, a pillow or two having already been placed in the bed opposite the point of maximal forward curvature of the cast. Simultaneously, the block and tackle is then slackened off and the patient is rolled over onto his back or, if the pillows have not been placed, he is rolled only onto his side in order to preserve the contour of the jacket while the plaster is still green. The plaster is then allowed to remain exposed to air to permit evaporation and hardening for about half an hour. If desired, a fracture board may be placed under the mattress.

The patient is then instructed to roll about as he pleases, always in the horizontal, never sitting up. He may be face down, on his

compress the posterior arch. The open space indicated in Fig. 28, *1*, between the anterior spines of the ilium and the hammock, is an index of adequate hyperextension. A sufficiently accurate gauge of clearance at this point is the width of the span of the hand.

(c) During suspension of the feet, the projecting spinous process can be observed or palpated. The prominence disappears during the process of elevating the feet.

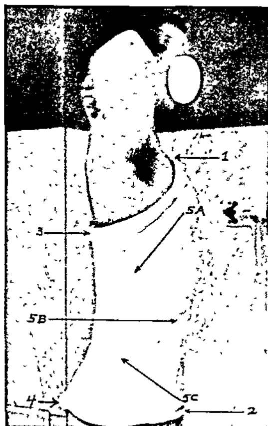


Fig. 29.—Typical hyperextension ambulatory jacket. *1*, Top, level of sternal notch; *2*, bottom at level of pubic crest; *3*, posterior top level clears lower angle of scapula; *4*, posterior bottom level with pubic crest; *5*, A, B, C, three-point pressure hold guarantees maintenance of hyperextension.

8. A plaster jacket is applied. The jacket is long in front, shorter behind, well modeled into the lumbar curve. Fig. 29 shows the essentials of a properly applied jacket. Plaster should be well modeled above the crest of the ilia to assure a firm, nontelescoping hold on the pelvis. The space pictured in Fig. 28, *1*, is awkward. As circular plaster is being applied, turns are alternately made around the torso and through the space. In addition, a plaster slab is introduced and made to fit snugly from the upper limit of the space to the pubic

rim. If this detail is thought out in advance, no difficulty is experienced. The plaster jacket must reach from the sternal notch above to the pubic rim below, posteriorly merely from the lower angle of the scapulae to the gluteal fold.

9. Fifteen to twenty minutes is allowed for the plaster to dry. The hammock is raised if necessary to permit replacement of the table top. After the leaves are in place, the stretcher is brought alongside, the hammock is slackened away and, resting his chest on the table, the patient is then rolled onto a pillow or shifted in the prone position. Meanwhile, the tackle lowers the legs.

10. The day following the reduction, a check roentgenogram determines the degree of reduction. If restoration of vertical height is insufficient, as measured by calipered comparison with the centrum above and below the involved one, another manipulation should be considered immediately. Re-examination of the original roentgenogram with those following the manipulation should be made to determine if obstruction to reduction can be detected (see Fig. 55).

If not, manipulation should be repeated, using foot suspension combined with a forward thrust at the level of the involved vertebra, but not directly against the posterior arch. This time, with the feet fully suspended and with more hyperextension than before, a forward thrust is made with the thumbs, 2 inches (5 cm.) lateral to the midline.

Very rarely is it necessary to manipulate again. The foot suspension method, using only gravity with the factors of horizontal traction and hyperextension leverage as described, may be expected to reduce completely uncomplicated crush fractures of the thoracolumbar region.

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The patient is then instructed to roll about as he pleases, always in the horizontal, never sitting up. He may be face down, on his

side, or on his back. He may rise to his elbows in order to eat since this merely extends him further.

Convalescence

After six weeks of such recumbency in bed, check roentgenograms are again taken to determine, particularly, vertical height in the lateral projection. The patient is examined for loss of weight and the question of a new jacket is entertained. Ordinarily, such a new jacket is not needed at this time. There is ordinarily no loss of weight. If the jacket has been made of proper dental plaster, its integrity can be depended on.

The patient is then allowed to be freely ambulatory, is encouraged to walk about as much as possible, preferably up to 2 miles a day as soon as he feels capable of this task. The object of ambulatory activity at this time is to induce perpendicular trabeculations in the callus. The vibrational influence of walking serves to induce the necessary trabeculations for unrestricted weight bearing. It is not only important to start walking at this time, but it is considered definitely harmful to keep the patient recumbent because, as is well known, structural trabeculations are the direct result of imposed strain.

Few patients exhibit lameness due to the hyperextension. Most patients do not require physical therapy other than the ordinary rehabilitation of the musculature through ordinary use. However, if lameness is a feature, postural exercises are given to develop the abdominal muscles. Obviously, the abdominal muscles have been overstretched due to the hyperextension. The patient is then instructed to sleep on his back with pillows under the knees and to reduce the size of the pillow under the head. A piece of plywood is put in between the mattress and the spring to make the bed somewhat firmer. This position allows the abdominal muscles to shorten and the spinal muscles to lengthen. The forward curve of the lumbar spine is thus reduced. The patient should be given double straight leg raising exercises, in order to develop power in the abdominal muscles. This, with the possibility of the necessity of some massage to the posterior musculature, ordinarily is sufficient, within a week or two, to rehabilitate the patient completely.

An additional criterion as to the status of the callus in the centrum is that of deep percussion or thumping over the spinous process. The involved vertebra remains tender to such deep percussion until complete structural restitution has taken place. Existence of such tenderness should constitute a sufficient reason to investigate

for detail and continue protection of some kind, whether it be a cast or a brace. Ordinarily, however, such tenderness is not experienced nor does lameness of the musculature persist; so that, at the end of three months, the average patient can go footloose and free and completely confident of a sound back.

There is ample proof of the fact that, on the average, if the sequence of steps has been carried out as outlined (that is, six weeks recumbent after the reduction; six weeks ambulatory, walking daily in increasing amounts, up to 2 or 3 miles a day, with adequate pro-

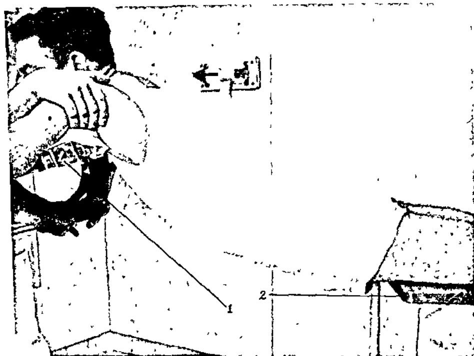


Fig 30.—Watson-Jones technic for reduction of uncomplicated crush fractures. *1*, Typical operating table being elevated the required amount; *2*, stationary table

tection, in a three-point pressure jacket) no collapse takes place. On the other hand, if ideal conditions do not exist, it may be well to continue protection for an additional month, or even longer, particularly if the patient engages in a hazardous occupation or if he is an undependable person. It will be noted here that details and sequences of convalescence vary considerably. Some surgeons use braces during convalescence. Removable braces, in the author's experience, are undependable at any time, since the patient ordinarily cannot be trusted to keep such removable apparatus in place at all times. Plaster casts are not removable; therefore they do not depend on the

patient's uninformed interpretation but, on the other hand, they insure hyperextension at all times, hyperextension being the critical position during all stages of convalescence. Sufficient statistical data regarding formation of callus following fracture of the vertebral body have not as yet accumulated to justify the assertion that the three months of protection are adequate to insure against subsequent collapse of the vertebrae. While this period has, with the author, become a rule of thumb resulting from a considerable clinical experience, nevertheless it is felt by many others that protection for a considerably longer time, recumbent (three months) and ambulatory with protection (three months) are essential to insure beyond the question of a doubt the future integrity of the spinal column.

Another technic for the reduction of thoracolumbar compression fractures is that of Watson-Jones. Fig. 30 shows the apparatus and mechanics and the hyperextension that is obtainable. A complete description of this technic is contained in Watson-Jones' book.

UNCOMPLICATED CRUSH FRACTURE OF MIDTHORACIC VERTEBRAE

For lack of a better method of delineating this region, it may be described as that part of the prominence of the thoracic curvature contained within the limits corresponding to the fourth to the ninth thoracic vertebrae inclusive. Again, from the standpoint of therapy, special mechanical considerations must be taken into account to attain hyperextension in this region. Compared to the thoracolumbar region just described, the midthoracic is relatively fixed, the leverage component is of greater importance and there is greater reason for limiting the therapy to the point of fracture. The apparatus consists of a low table, two standards to hold the irons and a pair of Goldthwait irons. Such irons can be made of properly tempered strap iron which can be molded with a pair of wrenches to exert forward pressure in the immediate region of the fractured centrum, or the irons can be made of spring steel and brought together with an adjustable mechanism (Figs. 31, 32). If the molded irons are used, a stockinet shirt is first applied. Scratchers (4-inch [10 cm.] muslin or gauze bandage) are drawn under the stockinet from top to bottom, anteriorly at the midline and posteriorly at the midline, and are left in place. (For later care of the skin, talcum is sprinkled beneath the stockinet and distributed with the scratchers by drawing the pieces of bandage back and forth over the surface of the skin, but underneath the stockinet.) The patient is rolled from the stretcher

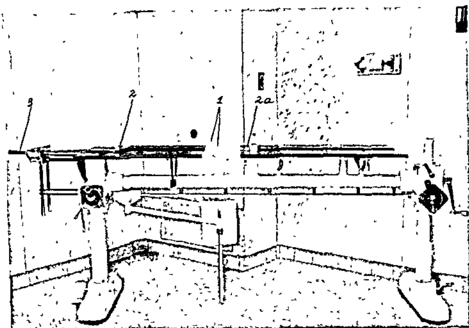


Fig. 31.—Apparatus with Goldthwait irons in place *1*, Spring steel straps, ¾ inch (about 2 cm.) wide; space between straps 2 inches (about 5 cm.); *2* and *2a*, holders for straps; *3*, crank to adjust curvature of straps.

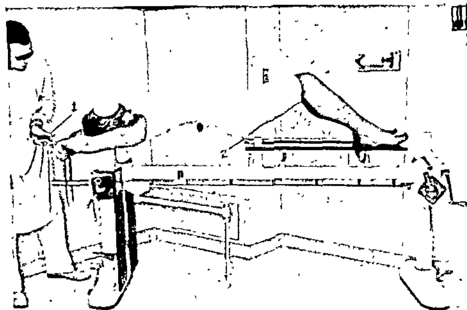


Fig. 32.—Hyperextension with Goldthwait irons. *1*, Crank squeezes irons into extension; *2*, irons.

onto the irons. He holds himself balanced by holding onto the table below and a plaster jacket is applied. It is necessary in using the irons to mold them so that the shoulder girdle and head are well be-

low the level of the fractured centrum. The component of traction is thus introduced from the summit of the curve of the iron to the head and foot of the patient. Care should be exercised to see that *such irons are not more than 2 inches (5 cm.) separated from each* other; otherwise the patient is very uncomfortable because of pressure of the irons against the bony prominence of the ribs. Very little difficulty is encountered in attaining complete vertical restoration if the arc of curvature of the irons is sufficient. Again, there is no need *for anesthesia or opiate. The recumbent, ambulatory, and rehabilita*tion periods are the same as for patients with the thoracolumbar type of fracture.

UNCOMPLICATED CRUSH FRACTURE OF UPPER THORACIC VERTEBRAE

Under this heading again there is reason for therapy designed for the anatomic peculiarities involved. The difficulties at this point are

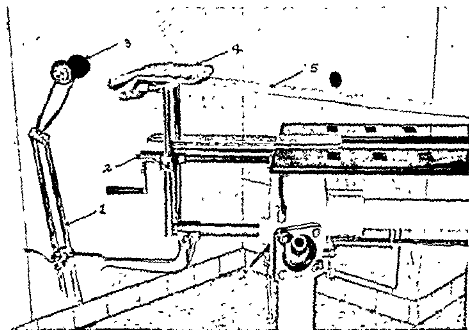


Fig. 33—Apparatus for treatment of high thoracic and bilateral cervical dislocation. *1*, Mechanism adjustable for height and for distance from end of table; *2*, tensor crank to adjust hammock; *3*, head rest; *4*, blanket or other cushion for hard edge of hammock rack; *5*, adjustable hammock.

those of both complete restoration of anterior vertical height and retention of vertical dimension once the vertebra is reduced. The superimposed head and neck tend constantly to move forward so that the head and neck must also be incorporated in the jacket. The ap-

paratus consists of a special table (Figs. 33, 34) in which the hammock is used up to the point of fracture and the head and neck are allowed to droop over an impinging edge.

If such special table is not available, alternate methods can be devised, such as laying the patient over the edge of an ordinary plaster table or over a crossbar mounted on the Goldthwait irons, providing there is free space beyond the end of the crossbar sufficient to allow sagging of the head and neck, or an improvised hammock similar to the one shown mounted on the fracture table can be used.

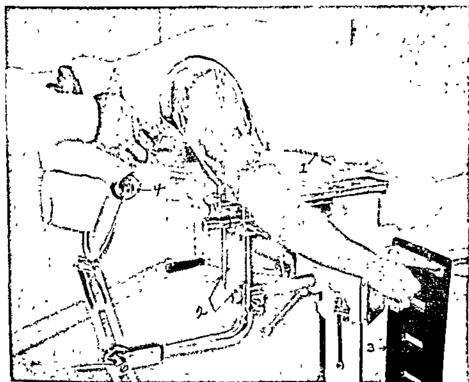


Fig 34.—Application of Minerva jacket *1*, Canvas hammock hidden by plaster; *2*, adjustable rack is elevated; *3*, table leaves lowered; *4*, head rest dropped; canvas hammock is withdrawn after plaster hardens.

The advantage of the apparatus depicted in the illustration is that, when it is properly assembled, the procedure is as quickly done as though the fracture were lower.

For the procedure under consideration, the *spinous process of the involved centrum must be marked.* As when the fracture is of the lower part of the spinal column, the patient again is rolled onto the hammock and a point is chosen 3 inches (about 7.5 cm.) lower than the mark. An assistant watches the patient from here on so that there is no shifting or sliding down in the hammock. The mark must always remain clear of the crossbar or point of impingement; other-

wise, there is danger of pressure on the spinous process of the involved vertebra. There is also the possibility of nullifying the mechanical purpose of the procedure since, if the bar were above the marked point, no useful leverage could be expected. A head rest must be supplied whether it be of pillows or other material or as illustrated (Fig. 34, *4*). The head and neck must be allowed to fall into extreme extension but only by their own weight. A Minerva jacket is then applied. The jacket obviously must reach from the crests of the ilia to the chin. Speed in the application of the plaster may be considerably increased by having a number of plaster slabs made as the circular plaster is being applied. Such plaster slabs pass around the head, if the head is to be included, unite the chest portion with the jaw portion and can be used both as back and front perpendicular pieces; all of this saves a good deal of the weight of the plaster and is therefore much easier to endure for the long period during which the patient must retain his position.

It is the author's opinion that in this region it is not as important to gain the last increment of vertical height as it is in the more movable sections of the spinal column, such as the cervical and lumbar portions. If, for example, it is found afterward that there is a 15 to 20 per cent loss of vertical height, it would not be considered important enough to attempt a more drastic method aiming at complete vertical height.

UNCOMPLICATED CRUSH FRACTURE OF THIRD TO SEVENTH CERVICAL VERTEBRAE INCLUSIVE

This region of the spinal column is very definitely delineated for therapeutic purposes. The medical profession should assume responsibility for the handling of fractures or dislocations of the cervical portion of the spinal column at the time those on ambulance service see the patient and should continue to be responsible until the patient is fully rehabilitated. Because of the increasing incidence of injuries of the cervical portion of the spinal column, due to the use of automobiles, the house officers and ambulance attendant need special instruction at the time they begin their service. The person in charge of first aid should first grasp the head and exert traction in extension; others can do the necessary lifting. The patient should be laid supine on the stretcher. One or two ordinary pillows, a folded blanket, a sandbag, or a folded coat can be placed under the shoulders and neck. The head is thus allowed to sag backward. The patient is then guarded by constant attendance at the head and is taken directly into the hospital bed, not to the roentgenologic room. A temporary

halter should be placed around his chin and occiput and 5 pounds (about 2.5 kg.) of traction applied. The head of the bed is elevated on blocks 12 inches (about 30 cm.) high, the head still remaining

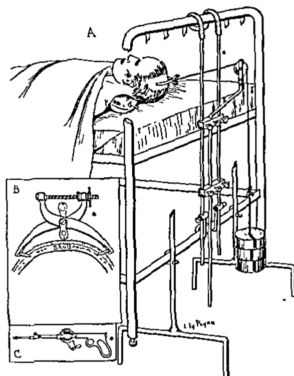


Fig. 35.—A, The tongs are applied transversely to the vertex of the skull, in a vertical plane passing through the articulations of the cervical portion of the spinal column. The tips of the mastoid processes are approximately within this plane and serve as satisfactory landmarks.

B, The tongs are designed so the traction bar can be used as a guide for correct placement of the points of the tongs. The traction bar is turned down and placed against the scalp with the arrow pointing to the midline of the skull. The points of the tongs are then lowered to the scalp and the points of contact are marked with a dye to indicate the level of the proposed stab wounds. The scalp is injected with procaine, and stab wounds large enough to admit the points of the tongs are made down to the skull.

C, Perforations of the outer table of the skull are prepared by using a small drill point, about 2 mm. in diameter, which is forced to a depth of approximately 3 mm. A special drill point with a fixed guard 3 mm. from the point has been employed to prevent excessive penetration. In the average adult skull, this technic should not give rise to penetration deeper than the diploe. Greater penetration is usually unnecessary. After the openings have been prepared, the points of the tongs are fitted into the bony perforations and are made secure by adjusting the thumb screws. When the tongs are properly locked, the points will not bore in (Crutchfield, W. G.: Surg., Gynec. and Obst., Vol. 63).

in hyperextension. Then a roentgenogram should be made with a portable machine, a lateral one only to begin with, in order to locate the region of involvement. Later, if special roentgenograms taken

through the mouth are needed to show fractures of the odontoid process or if roentgenograms of high segments of the spinal column are required to reveal fracture of the first or second cervical vertebra, these are made. If the involvement is in the region of the fourth, fifth or sixth cervical vertebra, however, as it commonly is, then Crutchfield tongs are applied (Figs. 35, 36). After the tongs have been applied, the head can be raised or lowered with a nicety im-

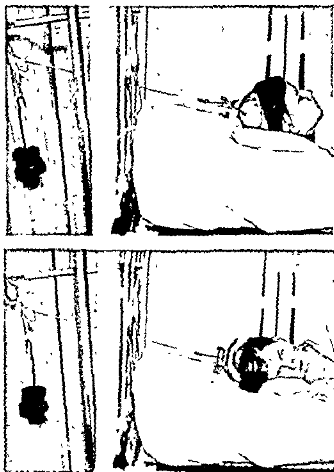


Fig 36—Traction control during change of position (Crutchfield, W. G.: Surg, Gynec. and Obst, Vol. 63).

possible with any but skeletal traction. The introduction of the tongs is completely painless and control of the head completely effective. Meanwhile, a careful neurologic examination will have been made; the procedure thus far has been aimed at the prevention of damage to the cord due to handling

It must be realized that in cases of fracture of the cervical portion of the spinal column, deformity probably is much greater at the time of the fracture than at the time a roentgenogram is taken. Recoil

already has taken place, so that more damage must be assumed than the picture would have us believe. If the head is completely under control, the patient comfortable and relaxed and the head in adequate hyperextension, most of the reduction already has taken place. For the average patient but 5 pounds (about 2.5 kg.) of traction is necessary. In occasional cases, up to 45 pounds (about 20.5 kg.) has been used. The head of the bed is elevated on blocks 12 inches (about 30 cm.) high in all cases of fracture of the cervical portion of the spinal column, so as to use the body for countertraction.

A simple crush fracture of a cervical vertebra ordinarily reduces itself with this simple traction by tongs in hyperextension with, in the average case, but 5 pounds (about 2.5 kg.) of weight attached. Strong arm methods are unavailing and may be damaging. Fractures of the cervical portion of the spinal column are treated with infinitely greater delicacy than fractures in regions lower in the spinal column. No difficulty whatever has been experienced in cases of simple crush fracture, not accompanied by paralysis, involving this region. The most frequent error seems to be that of insufficient hyperextension. Complete dependence can be placed on the anterior longitudinal ligament to prevent excessive hyperextension. (See footnote on page 104.) The patient simply lies on his back on an air mattress or a sponge rubber mattress and there is ordinarily no difficulty about his care in such cases, since the buttocks can be raised by the patient himself and the torso can be twisted somewhat without disturbing the region of fracture. Position is guaranteed by the skeletal traction. The usual cloth halters passing around the chin and occiput are very distressing, cannot be removed for shaving, usually result in pressure sores and keep the patient in a constant state of agitation. Crutchfield tongs are a complete answer to the question of treatment for uncomplicated cervical fractures. The patient simply remains with the traction apparatus applied a sufficient length of time for fibrous callus to form.

Several methods of fixation may be used as soon as the period of fibrous callus, approximately three to five weeks, has been reached. Fractures of other parts of the body may make awkward the prompt application of a plaster collar or Minerva jacket. If, for example, the femur has been fractured and traction apparatus is in place for the femur, it may be found preferable, from the standpoint of the patient's comfort, to await formation of firm callus in the femur before the tongs are removed and the plaster jacket is applied. When the time arrives to release the patient from the head traction, two dif-

ferent methods are eligible. A cast including the chin, occiput and upper half of the thorax may be sufficient, if properly applied, to hold the cervical portion of the spinal column well hyperextended throughout the ambulatory treatment and formation of structural callus. If, for one reason or another, use of such a short plaster case is deemed inadvisable, then recourse to the long jacket, extending from the crests of the ilia up to and including the entire head can be applied with the apparatus illustrated in Fig. 34.

If, for some extraneous cause, such as pneumonia, it proves desirable to have the patient ambulatory at a very early date, a bivalved plaster collar may be applied (Fig. 37). In this case longitudinal



Fig. 37.—Bivalved plaster collar. When bound together on the patient and buckled, this device prevents movements in flexion.

plaques or plaster slabs are laid over a piece of felt which has previously been fitted to the chin, neck and thorax so as to have a dependable hyperextension section in front, with the maximal amount of spread between the point of the chin and the thorax. With this completed, the tongs may be removed from the head, the anterior shell bound by a bandage around the neck and the patient rolled over prone. With the plaster half collar in place, the bandage is then removed and a shorter posterior half is made in the same manner over a piece of felt which already has been patterned to fit. By means of these two halves bound together with a buckle strap, it is possible to maintain complete hyperextension provided accurate fitting

and extreme hyperextension have been attained. The advantage of the split collar method is that it does not require removal of a patient to a table or other special apparatus which, before fibrous callus has formed, obviously would jeopardize the position of the fragments.

Convalescence

The period of convalescence in cases of fracture of the cervical portion of the spinal column is no different from that of other fractures of the spinal column. Three months is ordinarily the limit of fixation and, during the two to four weeks following removal of



FIG. 38.—Schanz collar. Stockinet 8 inches (about 20 cm.) wide and 72 inches (nearly 2 meters) long is employed; filler consists of twelve layers of 8-inch sheet wadding; cotton tape is used to tie; start under chin, wrapping snugly around neck; form to maintain necessary degree of hyperextension.

splintage, the necessary physical therapy is employed to limber the muscles of the neck. Frequently the muscles of the cervical region are painful during the period immediately after the splintage is removed. If so, a comfortable Schanz collar is applied (Fig. 38). In order to make such a collar, a piece of stockinet 72 inches (nearly 2 meters) long and 8 inches (about 20 cm.) wide is filled with a dozen layers of sheet wadding of the proper width. The ends are stitched and a piece of tape is sewn to one end. The collar is started under the chin, wrapped firmly around and around the neck and finally tied with the tape.

UNCOMPLICATED FRACTURE OF FIRST AND SECOND CERVICAL VERTEBRAE

Treatment of fractures of the first and second cervical vertebrae is very little different from treatment of fractures of the rest of the cervical portion of the spinal column. However, because of their structural individuality, these vertebrae must be considered in a separate group. By all odds, the most frequent injury at this point is that of dislocation involving the odontoid process and separation of the atlas from the axis. Perhaps the most exacting detail in the case of these two vertebrae is that of roentgenography. Modern high powered roentgenographic units are showing many more fracture lines in the atlas and the body of the axis than appeared a few years ago when such apparatus was not available. Odontoid fractures are easily exhibited through the wide open mouth, providing clear detail is shown of the atlanto-axial articulation. Since these joints appear at the same level as the base of the odontoid process; when a clear space is shown between the two components of the atlanto-axial articulation, the base of the odontoid process and its fracture line will be shown. Lateral detail will show more readily if the odontoid process has been displaced forward or backward, but if there is no displacement it may be very difficult to identify a fracture line. The anteroposterior view is much more dependable. During anteroposterior roentgenography, it is well to place a straight edge from the base of the occiput to the lower margin of the upper teeth. When these points are brought parallel to the straight edge and the straight edge is found to be perpendicular to the plate, the orientation is best to exhibit the odontoid process. In the absence of other evidence of fracture or dislocation in the neck and in the presence of failure at first to show fault in the first and second cervical vertebrae, it is well enough, because of the difficulty of roentgenography in this region, to make a second search, particularly if there is persistent muscular spasm. Again, providing neurologic evidence is lacking, fractures of the first and second cervical vertebrae are best treated with Crutchfield tongs. The same sequence obtains from the place of the accident to the hospital bed. Then comes halter traction, then the roentgenogram. Next, detailed roentgenography is applied and maintenance of traction in hyperextension, except when the odontoid process does not seem to come in right relation to the second cervical vertebra because it is found to be too far backward. In this case it may be necessary to eliminate hyperextension and to pull in a straight line, or even to introduce moderate flexion. These can easily be done with

Crutchfield tongs, by elevating the traction apparatus on the head.

On account of the large range of mobility between the first and second vertebrae, dislocation is practically always a feature. When fractures involve these two vertebrae, the patients are kept in position in bed for a considerably longer period than is necessary for crush fractures of the cervical portion of the spinal column. The odontoid process has little bony substance and the fragments present a very small fractured surface for the development of adequate callus formation. The movements of the head can very easily prevent union if the odontoid process does not fit accurately.

SUMMARY OF COMPRESSION FRACTURES

Fig. 39 represents differences in treatment based on the anatomic peculiarities of the region involved.

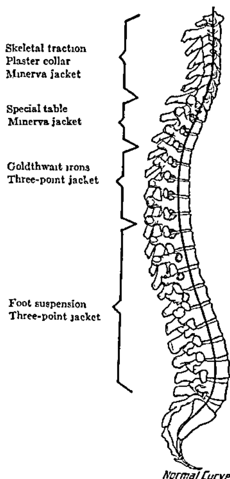


Fig 39.—The different methods of treatment used for simple, uncomplicated crush fracture, depending on the section of the spinal column involved (Deaver: Surgical Anatomy of the Human Body. The Blakiston Company).



Fig. 40.—*a*, Typical crush fracture of first lumbar vertebra; levers illustrate traction and countertraction exerted by vertebrae above and below affected one; *b*, same case as that represented in *a*, typical reduction by foot suspension

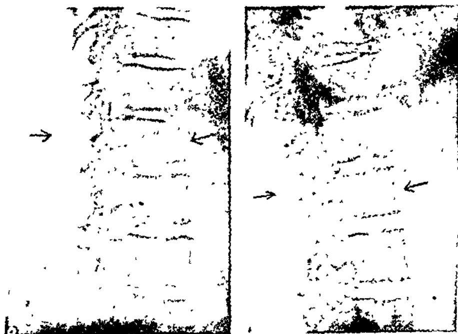


Fig. 41.—*a*, Very moderate, uncomplicated compression; reduction of the first lumbar vertebra with Goldthwait irons; *b*, result three months after reduction; note complete restoration of anterior vertical diameter.

Fig. 40, *a*, represents the levers, fulcra, and counteracting pull of hyperextension, and Fig. 40, *b*, the complete restoration of form and especially height ordinarily attained in cases of pure crush fracture as a result of foot suspension.

Fig. 41, *a* and *b*, shows a typical reduction with Goldthwait irons. In cases of fracture in which there is so little compression, reductions such as this are easily attained by this method.

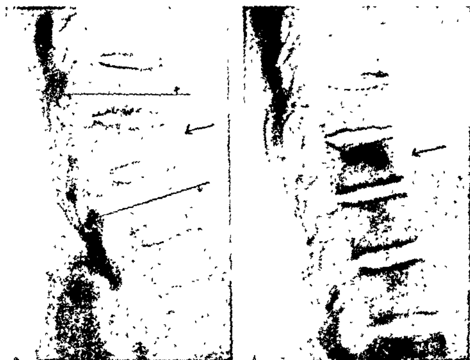


Fig. 40.—*a*, Typical crush fracture of first lumbar vertebra; levers illustrate traction and countertraction exerted by vertebrae above and below affected one; *b*, same case as that represented in *a*, typical reduction by foot suspension.

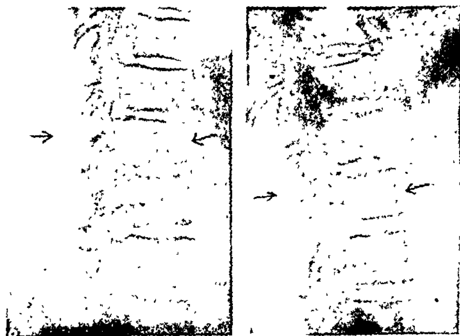


Fig. 41.—*a*, Very moderate, uncomplicated compression; reduction of the first lumbar vertebra with Goldthwait irons; *b*, result three months after reduction: note complete restoration of anterior vertical diameter.

CHAPTER VIII

FRACTURES OF SPECIAL GROUPS

Fractures of Spinous Processes

Fractures of the spinous processes are of small importance. Simple fixation of the region involved with a cross strap of adhesive tape, sufficient to guard against the extremes of mobility at the point, is ordinarily sufficient. If there is sufficient displacement, the distal fragment of the process can be removed under local anesthesia.

Fractures of Transverse Processes

Contrary to the opinion of a number of contributors of articles on the subject, transverse processes should be thoroughly immobilized until roentgenologic evidence of callus is present. Fractures practically always occur in the lumbar region and, due to contrary pull of the attached musculature, nonunion can occur easily. When such nonunion does occur, the region of the fracture of the transverse process is painful. It becomes extremely difficult to eliminate the cause of the pain because of the distance through the erector spinae muscles which must be traversed in order to remove the offending false joint. Because the occurrence of nonunion results in a painful back and because the condition occurs with sufficient regularity and gives rise to sufficient pain to cause prolonged disability, it is felt that patients who have fractures of transverse processes should not only be placed in a body jacket extending from the pubis to the upper part of the thorax, but the patient also should remain recumbent until there is roentgenographic evidence of union. Union occurs in from four to six weeks. It must be remembered that the crura of the diaphragm, the transversus abdominis muscle, the intertransverse muscles, the multifidus muscles and others of the spinal stabilizers originate from these processes. If the patient is up and about, the distal fragment is under constant motion due to voluntary and involuntary movement. If it becomes necessary to operate in a case of nonunion of a transverse process with painful disability, the process will be found, as compared with the posterior approach, much more easily accessible from a retro-

Hyperextension Fractures of Spinal Column

Fractures of this type are extremely rare because of the unusual conditions required to disrupt the spinal column with this kind of force. Nevertheless, extreme types of violence of this kind occasionally do occur. The structural iron worker may fall backward from 10 to 20 feet, striking an iron beam crosswise in the lumbar region. Thus, the leverage of the weight of both ends of the body is directed against the middle and a very serious avulsion fracture of the centrum is the result. It may happen that two 90 pound (41 kg.) levers representing the ends of the body, plus the velocity induced by the drop, combine to exert pressure at the moment of impact against a spinous process. This unusual conjuncture of mechanics has occurred, resulting in a transverse rupture of the anterior longitudinal ligament. The check strap effect of the ligament which safeguards the spinal cord against damage from hyperextension being destroyed, hyperextension is not only not effective but positively dangerous. Pull in a straight line, using the posterior ligamentous investiture as a check strap and application of the jacket under complete roentgenologic control, without hyperextension, may serve to restore nearly normal conformation of the fractured body. If, however, this avulsion type of fracture fails to respond to the closed method of treatment, open fusion may be indicated. The diagnosis of such hyperextension fractures may be immediately apparent from the lateral roentgenogram, in which an open space appears between the fragments of the centrum and the vertical height of the body is increased. This appearance should give the surgeon pause and, from this point on, extreme caution must be brought to bear for fear of dire and immediate results from ill advised treatment. When the anterior longitudinal ligament is thus horizontally ruptured, treatment by hyperextension may cause immediate paralysis.

Fortunately, the chance of encountering a hyperextension fracture is remote. Head-on collisions of automobiles involve hyperflexion. Falls from a height, unless the victim strikes back foremost some object that lies transverse to the vertical axis of the body, also result in hyperflexion or jackknifing. Cave-ins of earth also cause hyperflexion by squeezing. Obviously, careful analysis of how the injury occurred will serve as an indication that it is of the hyperextension type. Evidence of a contusion over a spinous process also will apprise the surgeon of the role of hyperextension in causation of the injury.

peritoneal approach, lateral to the erector spinae muscles and starting at the triangle of Petit; that is, an approach similar to that for lumbar sympathectomy or for the kidney.

Fractures of Articular Processes

Such a fracture may occur incidental to a crush fracture or to a fracture dislocation, or independent of such fractures. If a spinal column has been injured and the customary anteroposterior and lateral roentgenograms are negative, ordinarily the condition disappears with recumbency, strapping with adhesive tape or other appropriate treatment for muscle strain. If pain and tenderness at the point of the injury persist, the spinal column should be studied further. Repetition of the anteroposterior and lateral projections is indicated; then roentgenograms taken with the body rotated about 30 to 40 degrees, first on one side and then the other, may exhibit a fracture of an articular process. The plane of the thorax and the buttocks must be kept the same when such oblique roentgenograms are taken. However, as is stated elsewhere, the hope of discovering fractures of articular processes, laminae, or pedicles is remote indeed. Such fissure fractures are not ordinarily seen unless the periosteum is reflected. They are not important when associated with fractures of the body for the reason that, if the fracture of the body is properly handled and if the method of reduction of the body involves a component of horizontal traction, the usual fissure fracture in the lamina will be immobilized.

Fractures of Laminae

Direct violence against the spinous process from behind may fracture both laminae and may countersink the posterior arch sufficiently to cause direct pressure on the spinal cord and paralysis. Therefore paralysis and evidence of block, without fracture of the centrum, should indicate immediate resection or laminectomy.

Unilateral or bilateral fractures of the laminae obviously must be caused by direct violence against the spinous process and, if such a fracture has occurred and paralysis is present, the spinous process, with its laminae, should be explored immediately because it is obvious that the spinal cord is involved. Providing the patient's status otherwise permits, this operative procedure is imperative. It is thought that delay is extremely risky. Obviously, spinal puncture should be done to determine if the spinal fluid is blood tinged, and the Queckenstedt test for block should be made.

Injury of a disk so far has not seemed to feature as a cause of painful disability. The reason for this is thought to be that the usual site of extradural rupture of the intervertebral disk is at the point of the fourth and fifth lumbar intervertebral spaces. The incidence of fractures at this point is small. Higher in the spinal column, the intraspinal course of the nerve roots is much shorter; therefore, they are not exposed to intraspinal or extradural pressure.

Unilateral Compression Fractures

Compression fractures occur in which the centrum appears to show a double shadow in the lateral projection. Several of such cases have been seen in the last fifteen years. (See page 113, "Fracture Dislocations without Paralysis.") If such a double shadow is seen and in the anteroposterior view a deviation to the side is seen of the vertebra next above the one fractured, one must immediately suspect unilateral dislocation of the articular process. If further examination reveals that the usual space between the spinous process is altered, it makes the picture complete. Roentgenograms taken at 30 to 40 degrees show the articular processes more plainly and may be helpful in showing the jumped articular process. It is thought that such findings represent a spiral twist of the torso along with the usual flexion whiplash effect. Since the human vertebral column does not bend directly laterally without the accompaniment of rotation any more than a blade of grass bends with its width without twisting, this analysis of the mechanics involved when compression of one half of a centrum is greater than the other, is helpful in determining therapy. In such cases the operative exposure should be similar to that used in exposure for fusion. Such dislocations of articular processes are easily reduced during the first week. Later on, however, it will be found impossible to disengage the jumped process so that in such cases fusion must be performed later to yield a painless back.

The Intervertebral Disk

It is impossible to regard a compression fracture of the spinal column or fracture dislocation without considering the fate of the intervertebral disk. Plenty of evidence of a roentgenologic kind can be brought forward to show that the nucleus pulposus changes its position permanently as a result of a fracture or other injury to the spinal column. Narrowing of the intervertebral space is occasionally seen. Obviously, the annulus fibrosus must be ruptured or disarranged as a result of fracture lines running through the epiphyseal plate or the shifting of one vertebra on another, or the momentary increase of intranuclear pressure at the time of the accident. Rupture of nuclear material through fissures of the cartilaginous plate leaves a mark as a permanent alteration of the form of the intervertebral space, or as an area of rarefaction (Schmorl's nodule). By and large, the intervertebral disk, including its nuclear material, may be disregarded for the reason that the sequelae are such that they do not point toward the intervertebral disk as accountable for residual painful symptoms.

CHAPTER IX

DISLOCATIONS

UNILATERAL CERVICAL DISLOCATION

PURE dislocations are limited to the cervical portion of the spinal column. Unilateral dislocations in the cervical region affect largely the upper three vertebrae. Roentgenography may or may not exhibit



Fig 42.—Unilateral dislocation in the cervical portion of the spinal column. Note the difference in alinement of the upper series of three vertebrae with the lower series.

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conclusive evidence of unilateral dislocation. Usually, however, the lateral roentgenogram shows dislocation of the body somewhat forward while the anteroposterior roentgenogram shows disalinement. Again, because of the inability of the roentgenogram to show the posterior arch adequately, diagnosis by inference from the position of the head is necessary. The head is rotated toward the opposite side from the joint dislocated (Fig. 42). The head is also tilted away from the side of the dislocation.

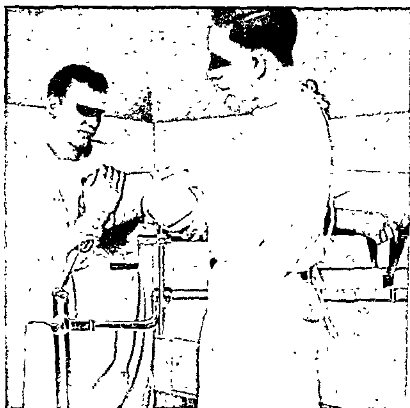


FIG. 43.—Apparatus for treatment of unilateral cervical dislocation. Walton method of manipulation in process.

It is realized that in the case of cervical dislocations, unless special study has been given to the subject by the surgeon, manipulations of any kind are fraught with danger. Attempts at reduction in all cases of cervical dislocations should be made with the Crutchfield tongs. The condition should be checked with roentgenograms frequently and hyperextension brought to bear at the right moment, when full extension and unlocking of the articular processes have been accomplished. Meticulous analysis in all cases in which patients are submitted to manipulation should be made before manual re-

duction is attempted. The Walton technic is unquestionably the superior method for the reduction of unilateral dislocations.

The patient is laid supine (Fig. 43). The aim is to use the well side as a fulcrum to rock or derotate the jumped process first upward, then backward, and then into typical hyperextension. In the case of a right dislocation, the right hand of the surgeon is wrapped around the right mandibular region, the left controls the occiput. With this hold and the patient lashed to the table, the head is tracted longitudinally, levered to the left, then simultaneously pulled backward and rotated to the right.

The left hand also may be shifted to a position alongside the lateral aspect of the neck on the well side. Strong pressure with this hand helps stabilize the fulcrum, being used as a pinion to lever the dislocated process up and over the one below.

Free movement of the head in all directions is the criterion of reduction. Extreme hyperextension, as in bilateral dislocations, must be maintained for at least four weeks for a firm ligamentous repair of the joint. If the dislocation is complicated by a demonstrable fracture line, three months of adequate splintage is considered necessary to prevent recurrence of painful symptoms. Such pain indicates recurrent dislocation.

BILATERAL CERVICAL DISLOCATION

For treatment of this condition,* the following must be provided: (1) traction in the exact horizontal position (Fig. 44), (2) countertraction through keeping the torso fixed, (3) a suitable halter for traction on the chin and occiput, (4) immediate application of a Minerva jacket, and (5) a portable equipment for making lateral roentgenograms. The fracture table, as illustrated, provides all the requirements for the manipulation and application of plaster. If such a table is not available, an ordinary operating table can be put in the Trendelenburg position with the patient lying supine. The patient is fixed to the table by passing straps of wide bandage around and above the shoulders and fastening the ends of these slings to a lower point in the table. As one visualizes the status of the spinal column with a bilateral dislocation (Fig. 45, a and b), the jumped articular processes must be tracted upward fairly forcibly and then the head must be dropped backward, still under traction, to a position of hyperextension. With this in mind, the Taylor method is used. A number of descriptions of this method are available. The descriptions all agree in principle, but vary somewhat in detail. At this point it is important

* With the warning given at the bottom of page 102 always in mind.

to remember the strength of the anterior longitudinal ligament.* Were it not for this ligament, damage to the spinal cord undoubtedly would ensue as the result of a longitudinal pull. Obviously, it would be a decided advantage to pull the head in flexion. Pulling in flexion, however, puts the maximal traction on the posterior roots of the cord. Therefore, it is decidedly unsafe to pull in flexion. Pulling longitudi-

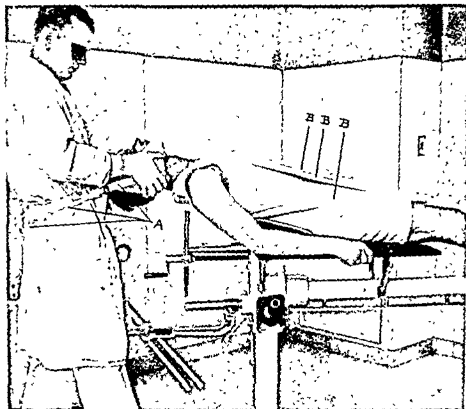


Fig. 44—Method of applying straight-line pull for bilateral cervical dislocation. A, Halter purchase on occiput and chin; note band extending around *buttocks of surgeon. B, countertraction bands lash shoulders to perineal post;* C, surgeon's foot abuts against stationary object on floor for better purchase.

nally with extension would, in view of the check-strap function of the anterior longitudinal ligament, provide a completely safe method of

* In a paper published in 1938 (Davis), results of a series of tests in seven cases were recorded. These ligaments were submitted to strains in a testing machine to determine stretch and breaking strength. The results demonstrated an average breaking point of 337 pounds (about 153 kg.) with no evidence of stretch. Tests to determine the amount of pull necessary to reduction showed 80 pounds (about 36 kg.) to be sufficient even when the patients were of the heaviest type. The resulting safety factor, therefore, is in the ratio of 4:1. Except, therefore, in cases of hyperextension injury or fracture dislocation, complete assurance may be felt regarding the ability of the anterior longitudinal ligament to withstand the strain of both the initial injury and the reduction.

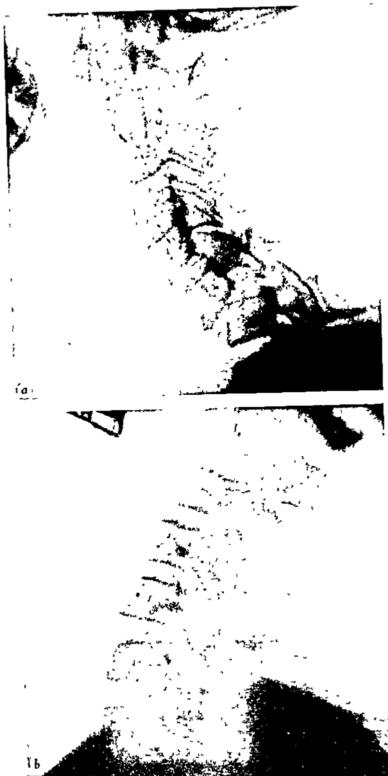


Fig 45.—*a*, Complete bilateral dislocation of the fifth cervical vertebrae forward on sixth; *b*, same case as that represented in *a*, after reduction by Taylor method

traction, but, unfortunately, the articular processes will not clear each other because the traction will be exerted principally on the anterior longitudinal ligament and the check-strap effect of the ligament will preclude the possibility of the jumped processes clearing the summit of the processes below. Therefore, *pull in the exact longitudinal axis of the body is highly important.* The use of the canvas sling around the surgeon's waist or buttocks, and attached to the halter, allows the surgeon the best mechanical advantage in handling the head. One hand is placed under the patient's jaw, the other under the occiput,

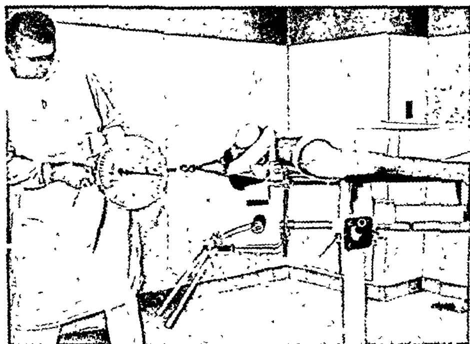


Fig 46—Interposed balance in line of traction to find traction strength of surgeon in pounds. If this is done, as a preliminary, against the end of the table and the surgeon pulls to his utmost, the safety factor can be determined in advance.

and one of the fingers of the hand on the occiput then is placed in contact with the cervical vertebra and its processes to determine crepitus. Ordinarily, *distinct crepitus can be felt when the articular processes disengage.* When this occurs, the head is brought into extreme hyperextension while full traction still is maintained on the head. *A lateral roentgenogram is then taken. If reduction has not taken place, another attempt at reduction should be made by using more traction.* It is interesting at this point to know how much one can pull *without doing damage. Several individuals were tested at* this operative procedure by using a spring balance (Fig. 46). It was

found that at the extreme of effort, the balance registered 80 to 125 pounds (about 36 to 57 kg.). Since the breaking point of the anterior longitudinal ligament is at weakest 160 pounds (about 73 kg.), and the average breaking point 337 pounds (about 153 kg.), it is obvious that pulling the utmost in the standing position, as illustrated, will not tear the ligament or otherwise disrupt the spinal cord or nerve roots, providing the traction is in a straight line and does not produce flexion, extension or lateral deviation.

The position in which the head and neck are placed in relation to the torso is of the utmost importance (Fig. 47). It must be re-

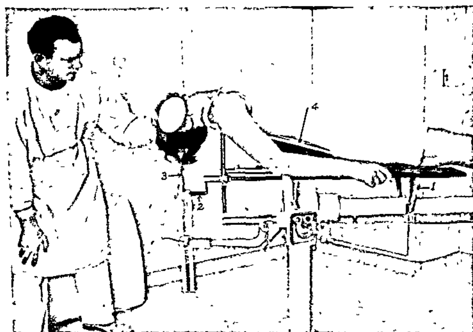


Fig 47.—After reduction of cervical dislocation; ready for application of plaster cuirass, *1*, brackets to hold table leaves; *2*, crank to make hammock tense; *3*, head rest permits extreme extension; *4*, lower level of jacket.

membered that, in order to dislocate the articular processes to the extent that they are completely jumped forward, the interarticular ligaments must be torn completely. In terms of the ultimate convalescence of the patient, it is imperative, therefore, that the cervical portion of the spinal column be hyperextended to its limit and fixed in this position so that the ruptured ligaments will unite in the short position; otherwise, the weight of the head will cause recurrence of the dislocation. In a number of cases of dislocation of this type, the dislocation has recurred shortly after the reduction or later in the convalescence, when the weight of the head and flexing of the head cause gradually increasing luxation. In such cases a fusion

operation is required to fix the spinal column. Perhaps the most important point about the application of plaster is to put the head and chin in such a position in relation to the thorax that the maximal amount of space exists between these points. Even at the cost of the patient's looking skyward when he becomes ambulatory, such hyperextension is necessary. The application of plaster on the fracture table illustrated is quick, easy and certain. If, however, one is confined to the use of an ordinary operating table and with an assistant holding the patient's head off the end of the table, a piece of felt is fitted to the skull, anterior side of the neck and the thorax in front in such a way as to conform to the line of the chin, neck and thorax, angle of the jaw, neck and shoulders. The felt is modeled to all the irregularities. The felt is then covered with plaster. After this section of the cast has been fitted, the patient may be shifted so that his shoulders hang off the end of the table, then the remaining portion of the thorax and circular portion around the head may be fitted This procedure forms a half jacket, which assures hyperextension of the neck. The patient may then be rolled onto a stretcher and a posterior section from the occiput over neck and shoulders is fitted. The anterior and posterior shells are then held together with a buckled strap. Either half may be removed for bathing while the other half remains to hold the reduction.

Convalescence

Ordinarily, the patient should spend a month in such a jacket, either ambulatory or recumbent, depending on the general status of the patient. The next day after the patient becomes ambulatory, lateral roentgenograms should be taken to see that the reduction is being fully maintained. After a month, providing there is no fracture, a plaster, cardboard or Schanz collar will maintain hyperextension for the next two to four weeks. Ligamentous structures do not require the period of fixation necessary for fractures, wherein structural callus is necessary. Physical therapy may or may not be necessary. Normal use is usually sufficient to limber the injured region.

CERVICAL LUXATIONS

Painful Injuries to Cervical Vertebrae Not Accompanied by Gross Dislocation

In a number of cases it is apparent from the history that a severe injury, such as that caused by the whiplash effect in some automobile accidents, has occurred, usually some time prior to the patient's first

visit to the office; painful symptoms referable to the cervical portion of the spinal column are present. Roentgenograms of such cervical spines fail to show definite evidence of forward dislocation of the body of a cervical vertebra (Fig. 48, *a* and *b*). There may be just sufficient luxation forward to suggest the possibility of a slight displacement of the magnitude of 1/16 inch (0.16 cm.) or more as one looks at the anterior line of the bodies of the vertebrae. The sig-



Fig. 48.—*a*, Typical partial dislocation of cervical portion of spinal column. Arrow points to slight forward displacement of body of fourth cervical vertebra. Note elimination of normal cervical forward curvature; *b*, same case as that represented in *a* Schanz collar in place Normal symmetrical cervical curve exaggerated (hyperextended). Discrepancy at fourth intervertebral space has been eliminated.

nificant finding, however, in the lateral roentgenogram is that the cervical portion of the spinal column has lost its normal anterior curve, and there is usually the slightest suggestion of a little angulation anteriorly at the level of an intervertebral space. It is well known that dislocation of a cervical vertebra that is of sufficient severity to sever the spinal cord can be reduced spontaneously by the patient's involuntary extensor recoil. It is assumed in these cases that the forward thrust is sufficient to sever the ligaments surrounding

operation is required to fix the spinal column. Perhaps the most important point about the application of plaster is to put the head and chin in such a position in relation to the thorax that the maximal amount of space exists between these points. Even at the cost of the patient's looking skyward when he becomes ambulatory, such hyperextension is necessary. The application of plaster on the fracture table illustrated is quick, easy and certain. If, however, one is confined to the use of an ordinary operating table and with an assistant *holding the patient's head off the end of the table, a piece of felt is* fitted to the skull, anterior side of the neck and the thorax in front in such a way as to conform to the line of the chin, neck and thorax, angle of the jaw, neck and shoulders. The felt is modeled to all the irregularities. The felt is then covered with plaster. After this section of the cast has been fitted, the patient may be shifted so that his shoulders hang off the end of the table, then the remaining portion of the thorax and circular portion around the head may be fitted This procedure forms a half jacket, which assures hyperextension of the neck. The patient may then be rolled onto a stretcher and a posterior section from the occiput over neck and shoulders is fitted. The anterior and posterior shells are then held together with a buckled strap. Either half may be removed for bathing while the other half remains to hold the reduction.

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is not sufficient to permit one to arrive at definite conclusions. It may be said, however, that in any case in which there is a history of a recent, or even a somewhat remote, severe accident, particularly of the automobile type, roentgenography should always be employed. If the lateral roentgenogram shows elimination of the cervical forward curve, this alone constitutes an anatomic change which is explained by the mechanism just described. If the patient is seen soon after the accident, a hyperextension collar is applied immediately. This not only restores the normal curvature but for the time being will exaggerate the normal anterior curve. If this treatment is employed, the patient will recover completely without operation. The collar obviously must be worn for several weeks or months.*

POSTERIOR DISLOCATION OF FIFTH LUMBAR VERTEBRA

A comparatively rare injury to the spinal column is posterior dislocation of the fifth lumbar vertebra at the lumbosacral joint (Fig. 50). This injury apparently occurs as the result of direct trauma to the back, which causes hyperextension. Unusual precautions must be taken in roentgenography at this point to demonstrate this condition. A diagnosis should not be made on the basis of one lateral roentgenogram. The condition is usually discovered as a result of searching for the cause of a disabled spinal column in which the symptoms are referred to this point and otherwise unexplained. A confirmatory roentgenogram should always be taken and the diagnostician should see that it is taken exactly perpendicular to the sagittal plane, in other words, exactly in the lateral position and centered directly at the lumbosacral joint. If the second roentgenogram shows that both the posterior and anterior borders of the vertebra are disalined with the sacrum below, that the fifth lumbar vertebra is posterior to its normal position and, of course, if no other lesion can be demonstrated, one has a right to assume that the posterior dislocation is causing the painful disability. Cases of this type of dislocation have not come under my observation immediately after the accident but I have encountered several cases in which severe trauma was a feature at the onset. The dislocation definitely was demonstrable and in each case fusion resulted in disappearance of symptoms. The fourth and fifth lumbar vertebrae should be fused to the sacrum.

In these cases the dislocation is universally accompanied by pain in the back and posterior part of the thigh, the same distribution as that observed in cases of spondylolisthesis.

* Attention is called again to the warning given at the bottom of page 102.

the posterior articular processes, that spontaneous replacement takes place with the recoil, but that the tear in the ligament does not undergo repair because treatment is not instituted. Subsequently, because of the incomplete repair of the ligamentous tear, the vertebra, through the weight of the head, gradually undergoes luxation forward. While the diagnosis and proof are not conclusive in such cases, it is safe to assume that the dislocation as outlined has occurred and that immediate splintage by the application of a collar to the hyperextended cervical spine is imperative to prevent gradually increasing luxation forward. In a period of years, the luxation would be sufficient to cause root pain and traumatic arthritis in the intervertebral joints, which, in turn, eventually would require fusion to eliminate the painful disability. Several cases of this type have been observed years after the occurrence of the injury. In all of the cases there was a definite history of a severe accident, but the symptoms at first did not appear to merit roentgenography.



Fig. 49.—*a*, Longstanding partial dislocation of third cervical vertebra forward on the fourth Note elimination of normal cervical forward curve; *b*, same case as in *a* Postoperative fusion. Third, fourth, and fifth vertebrae are fused to eliminate painful disability

In a case in point in which symptoms had been present for several years, fusion resulted in complete disappearance of root pain (Fig. 49, *a* and *b*). The number of these cases that have been reported

CHAPTER X

FRACTURE DISLOCATIONS

FRACTURE DISLOCATIONS WITHOUT PARALYSIS

UNTIL now, I have dealt with entities in which a well-charted course is profitable and good results are the rule. From now on, however, therapy is infinitely less certain, does not lend itself to definite charting, and is infinitely more dangerous. Throughout this chapter, the more dangerous pitfalls, as they have occurred in practice, will be pointed out.

Diagnosis by inference must be resorted to in cases of lesions of the posterior arch since the roentgenograms cannot be depended on to show even gross lesions involving the pedicles, the articular processes, and the laminae. One is frequently tricked into the illusion of a normally appearing posterior arch; fissure fractures, for instance, without gross displacement are impossible to exhibit by ordinary roentgenography. Fig. 51 shows a spinal column in which a number of defects of the pedicle and articular processes were made postmortem with a Gigli saw. A study of the four views of this spinal column shows but two defects. It is to be noted in this connection that the Gigli saw creates a considerably greater defect than does a simple fissure fracture.

Although it is generally known that a roentgenogram seldom shows all the lines of the fracture in a long bone, in the case of the posterior arch, the concealment of cracks and dislocations is much more effective than it is in a long bone because of the very dense bone which forms the accessory processes and the number of such processes, particularly in the lateral plane.

A glance at the spinal column shows how impossible it is to hope to reveal the fracture or dislocation by roentgenography because of the number of processes that have to be penetrated by the roentgen rays. In the lateral roentgenogram for instance, it is necessary to penetrate both lateral processes, four articular processes, and two pedicles. If a line of fracture is demonstrated, it is by the merest chance and it is necessary for the defect either to be large or the dislocation gross.



Fig. 50.—Posterior dislocation of lumbar portion of the spinal column on the sacrum Bilateral extension of pain along distribution of sciatic nerves. Fusion from fourth lumbar vertebra to sacrum in the deformed position relieved disability completely.

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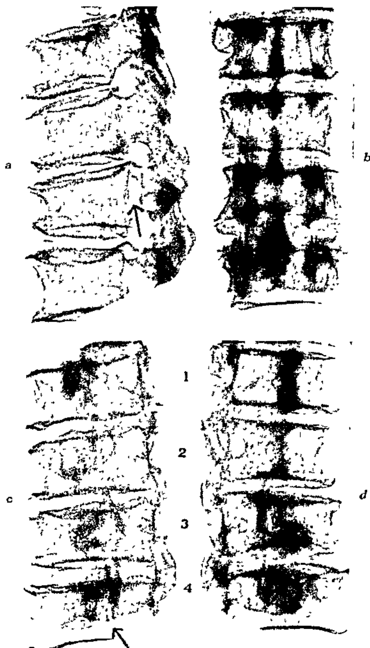


Fig. 51—Roentgenographic concealment. *a*, *b*, *c*, and *d*, Respectively lateral, anteroposterior, left, and right oblique projections of part of spinal column obtained at necropsy. Defects were made at various points in the posterior arch with a Gigli saw A sample of the defects created by the saw is indicated by arrows in *a* and *c* The other defects were of the same magnitude as those indicated by the arrows but are concealed by overlying dense bone. In *c* (left oblique) the following are notable: (1) intact, (2) defect made in tip of articular process but not clearly visualized in film; (3) intact, (4) explained above. In *d* (right oblique) defects were not clearly visualized in the films although they were made in all of the following structures· (1) articular process; (2) pedicle; (3) *pedicle*; (4) *articular process*

Roentgenograms taken at an angle of 30 to 40 degrees are more likely to exhibit fracture lines in the articular processes than are lateral roentgenograms. The majority of such oblique roentgenograms, however, cannot be expected to show much more than irregularity of the posterior articulations. The lack of visual evidence of fault in the posterior arch will continue to deceive most observers and undoubtedly will continue to create a false sense of security because of negative findings. No doubt, greatly increased caution is exercised by most surgeons in their approach to fracture dislocations with paralysis. It is the damaged cord in this case which warns the surgeon.

Fracture dislocations of fully as great magnitude, but without paralysis, occur regularly. In case of paralysis, one must assume risks which would not be warranted in simple crush fractures. The greatest danger, however, is that the surgeon may produce injury in a case of fracture dislocation without paralysis. Means of identifying the dangerous types of fracture dislocation without paralysis are as follows:

The roentgenograms must be observed from the point of view of damage to the posterior arch. With this approach in mind, certain points become immediately obvious. The correlation of a number of these points frequently will enable the surgeon to decide whether to employ manipulation or open operation. By observing all roentgenograms of spinal injuries in this light, the surgeon will safeguard himself against disasters owing to manipulation.

Fig. 52 shows an anteroposterior and a lateral roentgenogram made in a case of fracture dislocation of the first lumbar vertebra. No neurologic signs were present. The following findings were noted in the anteroposterior roentgenogram: (1) lateral angulation with its apex at the twelfth interspace; (2) a wide interval between the spinous processes of the twelfth thoracic and the first lumbar vertebrae; (3) a definite rotation of the entire upper section as indicated by the defective alinement of the spinous processes of the upper section with those of the lower section; (4) an unequal compression of the two halves of the body of the vertebra. The patient was a slender boy; therefore, roentgenography was at its best and showed clearly the articular processes.

The lateral roentgenogram revealed the following additional findings: (1) gross enlargement of the intervertebral foramen; (2) the appearance of one articular process being impaled on the one below; also the two different levels appearing in the centrum indicated at points 3 and 4.

Wherever this double shadow of the vertebra appears, the dislocation of one articular process must be expected. Fig. 53 is an exact replica of the injury just cited. When analyzed, this anatomic specimen shows the right inferior articular process of the twelfth thoracic vertebra displaced upward and forward and locked in front of the

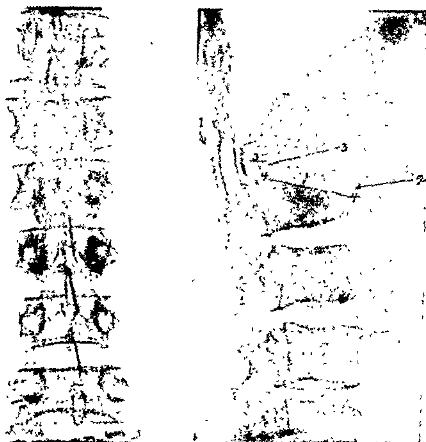


Fig 52.—Fracture dislocation of first lumbar vertebra. *a*, Anteroposterior projection observations. Note lateral angulation; wide space between spinous processes; different alinements of the series of spinous processes above and below the dislocation, unequal compression of two sides of body. Compare with *b*. *b*, Lateral view. *1*, A gross enlargement of the intervertebral foramen. Articular process of twelfth thoracic vertebra has become dislocated upward and is impaled on the superior articular process of the first lumbar vertebra *2*, Compression unreduced after attempt at hyperextension Impinging articular processes do not permit normal fulcrum of posterior joint to operate, therefore, disimpaction is impossible until processes have been disengaged. *3*, Level of one side of crushed centrum *4*, Lower level of opposite side.

right superior articular process of the first lumbar vertebra. It also discloses almost complete dislocation of the left inferior articular process of the twelfth thoracic vertebra.

An analysis of this specimen shows why the angulation, rotation

and disalinement of the spinous processes, with large interspinous space, all combine to make certain the diagnosis of a jumped articular process and demonstrates conclusively the impossibility of safely reducing such a dislocation by manipulation. *It is considered definitely* hazardous to attempt any manipulation at all. The sequence of treatment believed to be best for this type of dislocation is as follows:

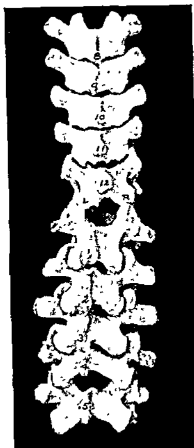


Fig. 53.—Demonstration of factors entering into diagnosis of fracture dislocation of lumbar region. Note (1) lateral tilting of twelfth thoracic vertebra; (2) different alinements of upper and lower series of spinous processes; (3) lateral angulation of two spinal segments; (4) rotation localized to point of dislocation as indicated by lateral offset of twelfth thoracic vertebra; (5) wide vertical separation of twelfth thoracic and first spinous process.

The patient is placed on an operating table which breaks in the middle or on a special fracture table, as in Fig. 54. The posterior arch is exposed by the subperiosteal method, as in fusion. The laminae and articular processes are exposed in detail. The table is then broken so as to induce the necessary flexion to disengage the jumped process. When using the special table, a sling is placed transversely un-

derneath the site of the fracture and flexion is induced by simply elevating the suspension apparatus until the process has room for clearance. A bone forceps then grasps the spinous process of the dislocated vertebra or a blunt elevator is used to pry the process into its proper position. Combining movements of posterior pull with rotation, the table is then straightened, the sling lowered, and the dislocation thus rather easily reduced.

With the operative wound still open, the patient is hyperextended by foot suspension and a lateral roentgenogram is taken in order to see that the centrum is fully restored to its vertical dimension.

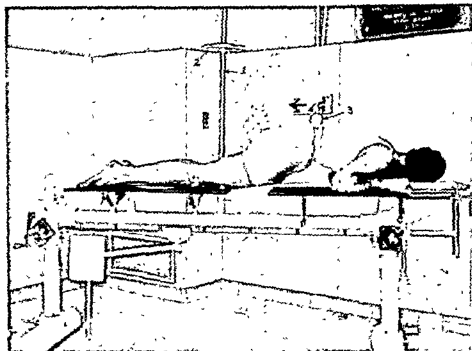
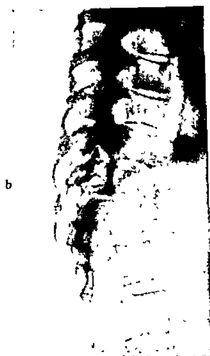


Fig. 54—*Apparatus for open reduction. 1, Telescoping post; 2, gear to adjust level; 3, canvas sling placed at level of fracture dislocation.*

Obviously, fusion is *not* necessary in such cases. If, however, the posterior arch is otherwise damaged, fusion may be indicated.

Fig. 55 illustrates a similar injury. In this case the spinal column was not exposed. The illustration shows most of the features necessary to a diagnosis of dislocation of the posterior articular process The roentgenogram, which was made six months after the fracture occurred, shows that the patient was saved from further gradual dislocation forward by a bony bridge existing between the two vertebrae in front. There is *practically no evidence of continuity of structure* of the posterior arch.





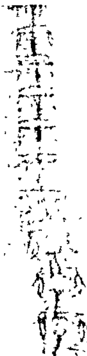


FIG. 55.—*a*, Fracture dislocation without paralysis. Note (1) gross enlargement of intervertebral foramen; (2) articular process caught on apex of process below; therefore, closed manipulation would be futile.

b, Lateral view after six months. Complete interruption of continuity of posterior arch. Note (1) inability to exhibit detail of articular process; (2) apparent bony bridge at anterior portion of body; (3) failure of reputedly strenuous attempts at hyperextension to decompress centrum or correct angulation.

c, Six months after fracture Note (1) lateral dislocation; (2) unequal compression between the two sides.

According to the history, a number of attempts were made to undo the deformity of the centrum by manipulation. Obviously, the centrum could not be opened to its complete height because of the resistance afforded by the jumped process posteriorly. It must be noted again that in neither of the cases represented in Figs. 54 and 55 were there any neurologic signs. Obviously, attempts at manipulation in such cases are extremely hazardous.

FRACTURE DISLOCATION WITH PARTIAL OR COMPLETE INVOLVEMENT OF SPINAL CORD

No exact line of demarcation can be drawn between simple crushing of a centrum without involvement of the spinal cord and the other extreme of complete shearing of the spinal column and cord, for which nothing can be done. No rule of thumb can be conjured to differentiate with certainty the case in which laminectomy is required from the one in which hyperextension only is required and the one in which both procedures are required.

A preponderance of evidence can usually be adduced for conservative or radical procedures. Experience in many hands proves, however, that laminectomy occupies a distinctly secondary place in the treatment of fracture dislocations with paralysis. Each case must be carefully analyzed and assessed on its own merits. Careful evaluation of the many factors involved usually will bring one to a definite conclusion as to therapy.

The usual factors to be considered as important in arriving at logical therapy are as follows:

1. A careful neurologic analysis to determine whether the paralysis is complete at a definite level or only partial.
2. Results of Queckenstedt's test.
3. The amount and nature of deformity in relation to the spinal canal and the question of its reducibility or irreducibility by manipulation or laminectomy or both.
4. An attempt to arrive at a conclusion based on neurologic findings and the results of the Queckenstedt test as to the probability of transitory edema, contusion, compression or transsection. Frequently, it is impossible to decide between these entities.
5. The element of time, which is urgent in relation to progressive paralysis, hematomyelia, compression or laceration.
6. The status of the patient, whether or not he can withstand an operation. It must be remembered in this connection that

in most cases of paralysis laminectomy can be done without general anesthesia.

The element of recoil at the time of the accident tends to reduce the fracture dislocation spontaneously. By the time the patient arrives at the hospital and the first roentgenogram is taken, the spinal cord may have been severed by a complete dislocation and complete spontaneous reduction may have occurred. In all cases, it is safer, therefore, to assume that the degree of displacement at the time of the accident was greater than the first roentgenogram would indicate. The record shows that in cases in which complete paralysis is present laminectomy is almost completely futile. The region involved has a decided bearing on the likelihood of recovery from a completely paralyzed status. Above the level of the second lumbar vertebra there is no ability of the cord substance to regenerate; below this level, the cauda equina possesses the power of regeneration. In doubtful cases, therefore, laminectomy is more applicable in the lumbar region than it is elsewhere.

When a case is encountered, however, it must also be remembered that hyperextension accomplishes an increase in all the diameters of the spinal canal and that if the Queckenstedt test discloses complete spinal subarachnoid block before hyperextension, but no block after hyperextension, laminectomy for the time at least may be postponed. Only in those rare cases in which the roentgenogram discloses impingement of a fragment of bone in the spinal canal is laminectomy imperative at the earliest moment. It is important to remember that neurologic examination should be made repeatedly. In cases in which such examination reveals increasing paralysis, laminectomy and possibly incision of the commissure obviously are indicated at the earliest moment. In the majority of cases, if the deep reflexes are obliterated, sensation lost, muscle action gone and the Babinski reflex absent, irreparable damage has been done. However, occasionally one observes a case in which hyperextension is instituted at a very early stage, and in which the neurologic signs point to a complete lesion, even with the presence of priapism and involuntary stools, and yet almost complete recovery takes place. It is this paradoxical clinical experience which demonstrates that conclusions regarding the status of the spinal cord are impossible to reach from a neurologic examination. Such recoveries can be explained only on the basis of contusion and localized edema of the spinal cord.

In effecting decompression, hyperextension probably is as efficient as, if not more efficient than, laminectomy. This is borne out by the following facts: (1) in cases in which complete paralysis apparently

was present immediately after the injury, recovery has followed the proper use of hyperextension; (2) in most cases of complete paralysis, laminectomy reveals pulpefaction of the spinal cord; (3) it frequently is difficult to determine with certainty whether the spinal cord has been destroyed or merely bruised; (4) laminectomy will not result in complete recovery unless the normal contour of the



Fig. 56.—Typical protrusion of posterior bony fragment sufficient to cause partial permanent destruction of cauda equina. Decompression laminectomy, six months after initial treatment, resulted in some improvement.

spinal column is reestablished; (5) regardless of the segment of the spinal column involved, it requires much less time to produce hyperextension than it does to perform laminectomy; (6) the usual compressing medium is the upper posterior angle of the involved centrum (Fig. 56); and (7) hyperextension opens the spinal canal to its greatest diameter at the site of the fracture. The fact that the use of hyperextension at the earliest possible moment after the patient

arrives at the hospital relieves pain, reduces deformity and opens the spinal canal to its largest diameter, whether it be skeletal traction for fracture dislocation in the cervical region or foot suspension for a thoracolumbar fracture dislocation, points to the helpfulness afforded by preliminary hyperextension. *If the patient is permitted* to assume any position he pleases while awaiting a decision as to when laminectomy is to be performed, every moment wasted in this manner increases the pain, shock, and hazard, whether or not laminectomy eventually must be performed. It would appear, therefore, that as a general rule, paralyzed patients should be put in a position of hyperextension immediately and, in the light of overwhelming statistical data against laminectomy, this procedure should be reserved for very carefully chosen cases. From my point of view, excluding the exceptional case of *fracture of the laminae with compression of the cord*, hyperextension by gradual or actual foot suspension, when the element of dislocation is the lesser feature, and skeletal traction in a position of hyperextension for injuries of the cervical region, should be employed the moment paralysis is observed. The Queckenstedt test is then executed. If sufficient hyperextension is exhibited in the roentgenogram and if spinal subarachnoid block is demonstrated by the pressure of the spinal fluid, laminectomy is considered but, if the anatomic repositioning is nearly perfect and if *the spinal canal appears to be open to its greatest diameter*, laminectomy is postponed and, in the great majority of cases of complete paralysis, it is never performed because of the known futility of the procedure. In most fatal cases, permission for necropsy has been granted and irreparable lesions demonstrated.

The segment of the spinal column containing the cauda equina is throughout considered more eligible for laminectomy than that part *of the spinal column containing the spinal cord proper*. Although very few patients will recover from complete paralysis, whether laminectomy or hyperextension is employed, the evidence that completely paralyzed patients have recovered almost complete function with hyperextension inclines me to the belief that as many or more will recover with hyperextension alone, providing laminectomy is always kept in mind in those cases in which there is increasing paralysis *or in cases in which reduction cannot be obtained by hyperextension*. In a number of cases, it will be found that the preliminary hyperextension followed by the making of shells is necessary *before* laminectomy is done.

The usual routine followed by the author in cases of complete paralysis is as follows:

1. Place the patient in optimal position to gain hyperextension immediately on entrance to the hospital.
2. Have neurologic examination performed, preferably by a neurologist or a neurosurgeon.
3. Apply Queckenstedt test at the earliest opportunity.
4. If there is no pressure response, apply hyperextension unless roentgenograms contraindicate its use.
5. Again apply Queckenstedt test. If return of pressure is demonstrated, decompression has taken place.
6. Repeat neurologic examination at intervals.
7. Meanwhile, apply proper urologic care.
8. If the fracture is irreducible by manipulation, exploration of the posterior arch may be indicated to reduce a jumped articular process.
9. A week will usually determine whether recovery will or will not take place unless the injury involves the cauda equina, in which case return of function may take place at a later period.

Hopeless Paralysis from Fracture Dislocation

If after the first few days it is found that no recovery is taking place, and the patient shows signs of total paralysis at a definite level, and if there is incontinence of urine and feces, the principal problem is that of nursing care. Urologic consultation should be had to decide the method of drainage, whether by suprapubic cystostomy or by allowing the bladder to become distended and thus produce an automatic bladder. It will be found that in order to prevent development of bed sores anterior and posterior shells should be made. These should be carefully modeled to impress the soft parts and should avoid the bony prominences. Such shells should extend from the knees to the shoulders and suitable apertures should be made anteriorly and posteriorly. The shells should be strapped together with trunk straps and the whole ensemble should be mounted on a Bradford frame. The patient should be turned two or three times a day, one shell being removed at a time in order to allow proper care of the skin. If the patient lives through the urinary complication, he may go on eventually to some sort of walking with crutches or may spend the rest of his life in a wheel chair.

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Note: For complete bibliographic references see papers referred to in this list as Nos. 2 and 3.



SECTION III

COMPOUND FRACTURES*

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* With some alterations the material in this section is taken from the third edition of the textbook on "Fractures, Dislocations and Sprains," by Key and Conwell, published and copyrighted by The C. V. Mosby Company, St. Louis, 1942.

CHAPTER XI

TREATMENT OF COMPOUND FRACTURES

FACTORS RELATED TO TREATMENT AND A CLASSIFICATION

A FRACTURE or dislocation is said to be compound when communication is established between the site of the fracture or inside of the joint and the outside air. The open wound leading down to the fracture may have been caused by external violence or it may have been caused by internal violence. In the latter type the rupture in the skin is made by the end of one of the fragments. Lacerations near a simple fracture may be misleading. In case of doubt as to whether or not a wound communicates with a fracture, it is well to remember that in compound fractures with small wounds, dark venous blood flows from the wound and can be forced out by pressing gently on the tissues and that minute droplets of fat from the bone marrow can usually be seen in this blood.

From the standpoint of treatment, the difference between a compound and a simple fracture is that a compound fracture is contaminated with bacteria which may be assumed to be pathogenic. This contamination occurs at the time of the injury and persists until such time as the organisms begin to grow in the tissues. From this time on the wound is infected.

Roughly, it can be assumed that a compound fracture becomes infected within from six to twelve hours after the injury. Consequently, injuries seen within the first six hours can be considered to be contaminated, and those seen after the first twelve hours should be considered infected, while those seen between six and twelve hours after the injury may or may not be infected and require surgical judgment if proper treatment is to be instituted. There are, of course, cases of virulent infection in which the infection starts within six hours after the injury, but these are unusual. Not only is the wound infected, but there is provided an ideal culture medium for the growth of pyogenic organisms because, as a result of the injury causing the fracture, there is always considerable damage and devitalization of the soft tissues, and interruption of blood supply.

The treatment of compound fractures includes the treatment of the patient at the scene of the accident, the transportation of the patient to a hospital or to some other point at which the injury will receive definitive treatment, and the treatment at the hospital. The last includes the treatment of the wound, the reduction and immobilization of the fragments in a position which will result in satisfactory function when and if union occurs, and whatever after-treatment may be indicated.

TREATMENT AT SCENE OF ACCIDENT

This will depend on the type of injury and also on where the accident occurs and on the facilities available for administering treatment. If the patient is not very severely injured, if there are no general symptoms, if the patient has to be transported only a relatively short distance before the injury can receive definitive treatment, and if this transportation can be carried out without further injuring the patient, no special treatment is necessary at the scene of the accident. However, a compound fracture is a surgical emergency and the patient should be transported to a hospital as soon as possible in order that treatment of the fracture may be instituted.

If the patient is seriously injured it is advisable that certain measures be taken at the scene of the accident in order to prevent further injury and the development of shock. Other things being equal, it may be said that the more severe the injury, the less the patient should be handled. In other words, the severely injured patient should be left on the side of the road and made as comfortable as possible until an ambulance arrives, instead of being transported some distance, placed in bed and then lifted again from the bed into some conveyance and taken to a hospital. Given a case of a man who has suffered a severe compound fracture of the leg or thigh in a highway accident, it is better that he be handled very little, that the extremity simply be straightened, that he be covered, kept warm and made as comfortable as possible where he is, and an ambulance sent for, rather than that he be carried into the nearest house where he will appear to be more comfortable once he is placed in bed. Handling of the patient necessarily causes pain, increases the amount of injury to the soft tissues, and tends to increase the amount of shock.

If the patient is bleeding and the bleeding is considerable in amount, it is very important that it be stopped as soon as possible by pressure, or by an improvised tourniquet if this can be applied.

In a case of compound fracture it is also important that the

wound be exposed and a clean dressing applied at the earliest possible moment. This dressing not only lessens the bleeding, but protects the wound from further contamination. If possible, sulfanilamide or sulfathiazole, or, preferably, a mixture of the two drugs in powdered form, should be sprinkled liberally in the wound before the dressing is applied. For this reason these drugs should be made available in emergency dressing stations in industrial plants, and also carried in ambulances which are sent out for the specific purpose of *picking up injured persons.* The placing of the chemical in the wound at this time can do no harm and will tend to decrease the rate of development of infection; while it may not be necessary if the patient is going to be operated on immediately, one can never be sure but that for some reason treatment will be delayed several hours, in which event the presence of sulfanilamide or sulfathiazole will greatly lessen the tendency for infection to develop, and will increase the possibility that surgical treatment will be successful.

It is especially important that severely injured persons be kept warm and dry, and that they be given fluids by mouth. Likewise, unless they are suffering from cerebral or intra-abdominal injuries, they should be given a hypodermic injection of morphine, or other opiate, as soon as possible after the accident and before they are transported to the hospital.

Splinting

The question arises as to what fractures should be splinted and how. At the present time there is a campaign on to apply splints at the site of the accident in all cases of fracture, before transportation is attempted. This, of course, can be carried to absurdity and much valuable time may be lost, or further injury may be done, by an unskilled person who attempts to splint a fracture before the patient is taken to the hospital. On the other hand, in cases of severe fracture in which the patients are going to be transported long distances, splints should be applied before the journey is started. This is because splinting not only tends to lessen the pain, but tends to prevent further damage to the soft tissues which may be incurred if the patient is transported without splintage, and tends to prevent the development of surgical shock.

Splints can be improvised at the scene of the accident if they are needed, and if commercial splints are not available (and they usually are not available). It is to be understood, however, that the application of these splints is not necessary in every case. In cases of fracture of the femur, or fractures of both bones of the leg, it is important that

splints be applied, if possible, before the patient is transported for any considerable distance. Likewise, severe fractures of the upper extremity should be splinted if transportation for a considerable distance is anticipated. In many instances it is sufficient merely to place the extremity on a pillow, or to bind the arm to the thorax, or to bind the lower extremity to its fellow.

It is important, in cases of fracture of the femur, that the lower extremity be immobilized on the pelvis and prevented from rotating. For this purpose, a Thomas hip splint is advisable, if one is available. However, it is rarely available at the scene of the accident, unless the accident occurs in an industrial plant with a well equipped first-aid station. However, by means of a long board splint, adequate fixation even without adequate traction can be improvised, and the patient can be transported safely and rather comfortably in an ambulance. In moving any broken extremity, manual traction should be made on the extremity before it is lifted.

TRANSPORTATION

The matter of transportation will depend on what is available and on the nature and severity of the injury. If the spinal column, pelvis or thigh has been injured, an ambulance is especially desirable. If both bones of the leg have been broken, an ambulance is also desirable. In cases of injury of the upper extremity, on the other hand, the patients usually can be transported in an automobile and are just about as comfortable as though they were in an ambulance; moreover, valuable time is not lost in waiting for an ambulance.

The patient should be taken to a hospital where he can receive adequate treatment; not necessarily to the nearest hospital, where perhaps the gravity of the situation and the importance of the time element are not appreciated, and where he may be placed in a bed to await the convenience of a surgeon. It is much more satisfactory to transport the patient a few miles farther in order that he may receive appropriate treatment. This is in spite of the fact that the time interval is of great importance, as not infrequently patients are rushed to the hospital only to be placed in bed and left for several hours before anything much is done for them.

TREATMENT AT HOSPITAL

Admission

The patient suffering from an injury should be admitted as expeditiously as possible and red tape should be cut to a minimum. Immediately after admission he should be examined by a physician

whose first duty is to estimate the general condition of the patient and decide whether or not he has been injured severely and whether or not he is in a state of shock or of impending shock.

In cases of compound fracture the time element is of great importance because the treatment of the wound is instituted in order to prevent the development of infection. The method of procedure at the hospital will depend on the facilities provided.

In the case of a severely injured patient, the first physician who sees him determines whether or not he is bleeding. If the patient is bleeding at an alarming rate, the first duty of the physician is to stop the hemorrhage if possible. In the hospital, this usually can be done by the application of clamps, a tourniquet or a pressure bandage. After the bleeding has been stopped, the history can be taken and the physical examination can be made. If the patient is not bleeding, the emergency dressing need not be removed until the patient is placed on the operating table.

History and Examination

The examination begins with a brief history of the accident and a notation of all the regions in which the patient complains of pain and disability: he may be suffering from multiple injuries and it is embarrassing to find one or more unrecognized and untreated fractures several days after the more obvious lesion has been treated. One should also include a notation of the number of hours which have elapsed since the injury, because this is an important factor in determining the method of treatment of a compound fracture.

The patient is then subjected to a brief physical examination. This includes the heart, lungs, abdomen and extremities. The injured part is examined more carefully and a tentative diagnosis is made. The temperature, pulse rate, and blood pressure are recorded, and an estimate is made of the patient's general condition. If indicated, a hypodermic injection of morphine or another opiate is administered at this time. This will not only tend to lessen the pain, but it is an important factor in preventing or minimizing surgical shock. As a rule, satisfactory dressings or splints are not removed until the definitive treatment of the fracture is started. The examination should include the making of satisfactory roentgenograms of the injured part unless the patient is in shock. If surgical shock of considerable gravity is present, it may be advisable to defer the roentgenologic examination until after the patient has reacted favorably to the treatment of the shock. If severe shock is not present, the patient may be taken directly to the operating room from the roentgenographic room.

Treatment of mild shock can be started in the operating room and continued during the operation.

Treatment of Patients in Shock

Traumatic shock is indicated by unusual pallor and sweating, a cold clammy skin, pinched facies, dilated pupils, shallow respiration, rapid, thready pulse, subnormal temperature, and low blood pressure. If the shock is chiefly due to hemorrhage, restlessness and air hunger may be present. Shock, on the other hand, should be distinguished from fainting. This may superficially resemble shock, but the patient who has fainted will recover quickly if placed in a recumbent position.

It is a question whether surgical shock or a severe injury should receive the primary treatment. Some surgeons maintain that immediate treatment of the injury is the most efficient method of treating the shock. On the other hand, I believe that if the shock is at all serious it should receive the first attention, and that the delay of an hour or a few hours in treating the injury will not greatly enhance the danger of infection. This is particularly true since the introduction of the sulfonamide drugs, which lengthen the time during which débridement and suture of the wound can be done with safety.

The patient in shock should immediately be put in a quiet room in a warm, dry bed with heated blankets both under him and over him, and he should be surrounded by hot water bottles. Particular care should be taken not to burn the patient with the hot water bottles, as patients in shock are burned easily. The foot of the bed should be elevated so that the patient is in the shock position. A full dose of morphine should be administered. The patient should be given fluids by mouth if he can take them, and usually he should be given fluids intravenously as soon as possible. If plasma is available, a transfusion of plasma can be given immediately. On the other hand, if plasma is not available, a 5 per cent solution of dextrose can be given intravenously (an adult receives 1000 cc.). Blood should be taken for matching, and a suitable donor obtained. The patient should be given a transfusion of 500 cc. of whole blood if he does not react promptly to these measures. If the condition is grave, oxygen can be administered and this will help combat the anoxemia. Fractures of the extremities should be immobilized with sand bags or splints, if this has not been done before the patient entered the hospital.

The treatment of the shock, therefore, consists of relief of pain by morphine, rest of the injured part, restoration of body heat by hot blankets and external application of heat, rest of the patient by recumbency in the shock position and isolation, administration of

fluids or blood to restore blood volume and increase blood pressure, and, in severe cases, administration of oxygen to combat anoxemia.

As soon as the patient reacts favorably, treatment of the fracture can be undertaken. This includes the making of roentgenograms as the patient in shock should not be transported to the roentgenographic room before he is treated for shock.

Antitetanic Serum and Gas Gangrene Antitoxin

Any compound fracture may be complicated by tetanus, and this is much more easily prevented than cured. Consequently, if the patient has not received tetanus toxoid, antitetanic serum (1500 U. S. A. units) should be given subcutaneously and its administration recorded immediately; otherwise, in the press of duties incident to treating the fracture it may be forgotten. The large dose should be used in the presence of severely contaminated wounds and should be repeated at intervals of seven days until three doses have been given. If anaphylaxis is feared, the serum should be given in graded doses at intervals of thirty minutes, beginning with a dose of 0.5 cc. In cases of severe injury, the polyvalent gas gangrene antitoxin should be administered as a prophylactic measure. The usual prophylactic dose is 1 ampule of the combined prophylactic tetanus-gas gangrene antitoxin, which generally contains the indicated units of antitoxin of the following organisms: B. tetani (Cl. tetani), 1500; B. perfringens (Cl. welchii), 2000; vibrion septique (Cl. oedematis maligni), 2000. The polyvalent therapeutic antitoxin of Lederle, which in the presence of severe infection may be used prophylactically, contains the indicated units of antitoxin of the following organisms: B. perfringens (Cl. welchii), 10,000; vibrion septique (Cl. oedematis maligni), 10,000; B. oedematiens (Novyi) (Cl. oedematiens), 1500; B. sordelli (Cl. oedematoides), 1500; B. histolyticus (Cl. histolyticum), 3000.

All personnel of the Army is immunized actively against tetanus by vaccination with tetanus toxoid (plain). The initial series of injections is given as soon as possible after each individual enters the service. It consists of three subcutaneous injections of toxoid at intervals of three to four weeks, each injection being 1 cc. in amount. A stimulating dose of 1 cc. normally will be given at the end of the first year only. However, if an individual is to depart for a theater of operations he is given a stimulating dose of 1 cc. unless such departure is within a period of six months subsequent to the stimulating dose given at the end of the first year. The record of tetanus vaccinations is stamped on the identification tags of the individual. Immunity lasts from six months to five years. Untoward reactions are rare. An emer-

Treatment of mild shock can be started in the operating room and continued during the operation.

Treatment of Patients in Shock

Traumatic shock is indicated by unusual pallor and sweating, a cold clammy skin, pinched facies, dilated pupils, shallow respiration, rapid, thready pulse, subnormal temperature, and low blood pressure. If the shock is chiefly due to hemorrhage, restlessness and air hunger may be present. Shock, on the other hand, should be distinguished from fainting. This may superficially resemble shock, but the patient who has fainted will recover quickly if placed in a recumbent position.

It is a question whether surgical shock or a severe injury should receive the primary treatment. Some surgeons maintain that immediate treatment of the injury is the most efficient method of treating the shock. On the other hand, I believe that if the shock is at all serious it should receive the first attention, and that the delay of an hour or a few hours in treating the injury will not greatly enhance the danger of infection. This is particularly true since the introduction of the sulfonamide drugs, which lengthen the time during which débridement and suture of the wound can be done with safety.

The patient in shock should immediately be put in a quiet room in a warm, dry bed with heated blankets both under him and over him, and he should be surrounded by hot water bottles. Particular care should be taken not to burn the patient with the hot water bottles, as patients in shock are burned easily. The foot of the bed should be elevated so that the patient is in the shock position. A full dose of morphine should be administered. The patient should be given fluids by mouth if he can take them, and usually he should be given fluids intravenously as soon as possible. If plasma is available, a transfusion of plasma can be given immediately. On the other hand, if plasma is not available, a 5 per cent solution of dextrose can be given intravenously (an adult receives 1000 cc.). Blood should be taken for matching, and a suitable donor obtained. The patient should be given a transfusion of 500 cc. of whole blood if he does not react promptly to these measures. If the condition is grave, oxygen can be administered and this will help combat the anoxemia. Fractures of the extremities should be immobilized with sand bags or splints, if this has not been done before the patient entered the hospital.

The treatment of the shock, therefore, consists of relief of pain by morphine, rest of the injured part, restoration of body heat by hot blankets and external application of heat, rest of the patient by recumbency in the shock position and isolation, administration of

with an antiseptic substance and the patient is given *sulfathiazole or sulfadiazine* by mouth.

Since the local use of the sulfonamide drugs has permitted surgeons to operate on bones with greatly increased safety, there is no reason why patients who have sustained fractures which are compounded from within should not receive the benefits of operative treatment and also the further guarantee against infection which can be obtained by implanting sulfonamide drugs in the wound.

If the patient is suffering from a compound fracture and is not in shock, he is taken to the operating room as soon after he has been admitted to the hospital as is practicable. He should first be taken to the roentgenographic room or a portable machine should be used to make roentgenograms of the injury. These should then be sent to the operating room. If severe shock is present, this should be treated first and the patient should not be moved to the operating room until he begins to react favorably. In the operating room, if the patient's general condition is satisfactory, pentothal sodium or evipal soluble may be administered intravenously to produce general anesthesia, or inhalation anesthesia or local anesthesia may be used, depending on the choice of the anesthetist and the surgeon.

The patient should be placed on the operating table without removing his emergency dressing or splint if this has been applied. If he is in a serious condition, general anesthesia should not be started until the operating room and team are ready, because it is advisable not to prolong the anesthesia more than necessary.

Before proceeding with the preparation of the skin or the operation, a tourniquet may or may not be applied. It has the following advantages: (1) it conserves the blood supply of the patient, and (2) since it enables the surgeon to work in a relatively bloodless field, he has a better view of the damaged tissues and is able to remove foreign material more thoroughly and to work more quickly than when bleeding is present. However, the tourniquet is removed at the end of the débridement, before the sulfonamide drugs are implanted in the wound and before an attempt is made to suture the wound, because it is important to stop all important bleeding before the wound is sutured and, in completing the débridement, the presence of bleeding from the cut muscle is of aid in determining whether or not the tissue is viable. In applying the tourniquet the limb should be handled as gently as possible, and if a pneumatic tourniquet is available, it should be used. If a tourniquet is to be used it should be applied before preparation of the skin is started.

On the operating table the skin is prepared as for a clean surgical

gency stimulating dose of 1 cc. of tetanus toxoid is administered to any previously vaccinated individual who incurs a battle wound or burn, or any nonbattle injury which is likely to be complicated by tetanus, or who is to undergo a secondary operation for which the surgeon deems tetanus toxoid advisable.

All personnel of the Navy is also immunized actively against tetanus, but the system differs in the following respects from that employed in the Army: (1) alum precipitated toxoid is employed instead of plain toxoid; (2) each dose is 0.5 cc. instead of 1 cc.; (3) the initial series consists of two injections at intervals of four to eight weeks, and (4) a stimulating dose of 0.5 cc. is given at the end of one year or if the individual is wounded.

Treatment of Wound and Fracture

If a compound fracture is present, not only must the fracture be treated but usually it is advisable to treat the wound by débridement. This means an emergency operation.

What compound fractures should be treated by débridement? The answer to this question will vary with the individual surgeon. The fracture may be compounded from without—that is, by the fracturing force, in which case the overlying tissues have been crushed, more or less devitalized, and foreign material including clothing and dirt may have been carried into the wound—or the fracture may have been compounded from within, particularly if the injury is due to indirect violence, and the wound in the skin may have been produced by the end of one fragment sticking through the skin. In such instances the fracture is relatively clean, unless the end of the bone has been contaminated, usually by coming in contact with the ground or pavement.

In the past it has been my custom to employ débridement in all cases of compound fracture in which the compound wound was caused by external violence—that is, fractures compounded from without, except those due to bullets traveling at high speed—and not to employ débridement in cases in which the fractures were compounded from within unless the bone appeared to be contaminated or unless there was good reason to believe that the bone had been contaminated and then pulled back into the tissues. However, with more experience in the use of the sulfonamide drugs implanted locally in the wound I have changed my point of view and now use débridement in the treatment of all compound fractures, except those caused by high-speed bullets. These fractures are not treated by débridement because the bone is comminuted and such fractures tend to respond better if treated as simple fractures, except that the wound is painted

usually slips into the wound and the strip is divided at some point. When this happens the further excision of the margin of the wound is carried out, beginning a short distance back of where the knife slipped in, so that all of that portion of the skin which is included in the margin of the wound is removed. At the same time, if there is an adjacent region in which the skin is grossly devitalized by contusion, so that it is perforated in small portions and ground down or crushed until it is paper thin, this region is also excised, because if it is left it will slough and tend to cause infection. However, no skin should be removed unnecessarily, especially if the wound is to be closed, because it is important that the wound be sutured with as little tension as possible, and this cannot be done if wide excision of the margins of the wound is practiced.

If more than one wound is present, the skin of each wound is excised in succession at this stage of the operation. The knife and forceps used in this maneuver are then discarded because they are grossly contaminated, but it is not necessary for the surgeon to change gloves, as they have not touched the contaminated tissue.

Enlargement of Wound.—The wound is enlarged by incisions up and down in the long axis of the extremity, the margins are retracted and the depths of the wound are inspected. The degree of enlargement will depend on the size and depth of the wound and the damage to the underlying tissues. The longitudinal incisions are not made any longer than necessary. While it is true that wounds heal from side to side and not from end to end, it is also true that, other things being equal, small wounds cause less pain and heal with fewer complications than do large wounds. As the wound is enlarged, blood vessels which are seen or are bleeding if the tourniquet is not on are clamped either before or immediately after they are divided, care being taken to make sure that as little blood is lost as possible. The large vessels are ligated. The wound should be enlarged sufficiently to permit exploration of the entire damaged region when the edges of the wound are retracted.

Débridement of Wound Proper.—It is now possible to inspect the depth of the wound and to estimate the damage to the deep structures. The surfaces are carefully sponged. Any foreign material or foreign bodies which are seen are removed. Not infrequently, the skin and fascia have been stripped and separated in layers, and the resulting deep pockets should be explored. It is usual to excise a thin layer of the superficial fat and fascia which may be exposed around the margins of the wound, and to excise a thin layer of the exposed muscle which forms part of the walls of the wound. Like-

operation; an adequate field around the wound is cleaned and sterilized either by the dry or by the wet method. In using the dry method, the wound is covered with a clean, dry dressing and the skin is washed with benzene or ether and shaved as close to the margins of the wound as possible. The skin, not the wound, is then painted with a cutaneous antiseptic substance—tincture of iodine, merthiolate, metaphen, tincture of mercresin, or whatever antiseptic preparation the surgeon prefers.

In using the wet method the skin wound is covered with a clean, dry dressing and the surrounding skin is washed thoroughly with soap and water, and shaved. The shaved portion should extend as close to the edges of the wound as possible, and should be of sufficient size to allow an adequate operative field. After the limb has been shaved and washed with soap and water, it is then washed with benzene or alcohol or ether; after this has dried or evaporated the skin, not the wound, is painted with whatever cutaneous antiseptic substance the surgeon prefers, as mentioned previously in the description of the dry method. This preparation of the skin and of the operative field must be performed by the surgeon with sterile gloves, *unless he is fortunate enough to have a well-trained assistant who* can be depended on to carry out the procedure with care and gentleness. If the wound contains dirt or grease, it should be washed with soap and water. The surgeon then dons a clean gown and gloves.

Having been prepared, the limb is now pulled straight, supported on sand bags or by traction, and draped with sterile sheets and towels so that an adequate portion is exposed for the operation.

The type of débridement varies among individual surgeons. Some surgeons believe that it should include block removal of all the surface of the wound which is exposed; but this is rarely practicable. Others merely enlarge the wound, pack it open and remove any gross foreign bodies which may be present.

The following outline of the operation is one which will be successful in most cases, and one which does not sacrifice any tissue unnecessarily. It is carried out in a series of steps which may be enumerated as follows:

Excision of Skin Margins.—With toothed forceps the skin at the margin of the wound is grasped, and with a knife a thin strip of skin is cut away entirely around the wound. This strip is rarely more than ¼ inch (0.6 cm.) wide. It includes the skin and any subcutaneous tissue which may be adherent to the skin, but no effort is made to carry this incision into the depths of the wound. If possible, the margin of the wound is excised in one piece. However, the knife

not act as a bone graft which is firmly fixed to the bone which it is supposed to aid in uniting.

Rarely, in cases of epiphyseal separation the end of the shaft has been forced out of the wound, and has become contaminated by being driven into the dirt or by forcibly coming in contact with some other foreign substance. This epiphyseal surface or end can be forcibly scrubbed with soap and water rather than excised and can then be reduced. Healing then may be expected to occur without deformity and without infection.

The débridement is now complete. The edges of skin have been excised, all visible foreign material has been removed from the wound, all grossly contaminated and devitalized tissues have been excised, and bleeding vessels have been ligated. In other words, the toilet of the wound is complete from the standpoint of mechanical excision.

Irrigation of Wound.—It is now advisable to irrigate the wound with warm physiologic salt solution. This does not mean a prolonged irrigation, using several gallons of salt solution. As a rule, 2 quarts (2000 cc.) are sufficient. The solution is placed in the irrigating can held by an assistant and to this is attached a rubber tube without a glass nozzle. The force of the flow is controlled by raising or lowering the height of the can and by squeezing the tip of the rubber tube so that the salt solution can be squirted into all portions of the wound. This will tend to separate loose tissue, especially areolar tissue, and may bring to light and remove foreign material which may have been missed during the preceding stage. After this irrigation is complete the wound is sponged, rendered relatively dry, and is again inspected for the presence of any foreign bodies or devitalized tissue. If any are found they are removed.

Repair of Deep Structures—At this stage muscles, tendons, and nerves which are found to be cut or torn are repaired. If torn ends have been excised during the preceding stage of the operation, they are now carefully brought together and sutured with fine silk or catgut. Muscles are sutured very loosely, just enough suture material being used to hold the ends in contact. Nerves and tendons are carefully sutured with fine silk. It may be advisable in the case of both tendons and nerves to excise a small bit more from each end in order that accurate approximation of healthy tissues may be obtained.

Reduction and Internal, or Pin, Fixation of Fracture.—By manipulation of the extremity or of the ends of the fragments with bone-holding forceps, the fracture is now reduced as accurately as possible.

wise, severely damaged muscle which does not contract when pinched, or does not bleed if the tourniquet is not applied, is excised. However, wide excision of undamaged muscle should not be done if this can be avoided. Not infrequently, masses of areolar tissue will contain small foreign bodies or dirt. It is advisable to excise such areolar tissue, rather than to attempt to pick out small bits of foreign material. If shreds of periosteum have been torn off and contaminated, these are excised. Vessels which bleed after the clamps have been removed should be ligated with fine silk or catgut.

At the end of this stage of the operation, the wound should be relatively clean, and should not contain visible foreign bodies or unexplored pockets. All grossly damaged and devitalized tissues have been excised with a sharp knife. The wound should contain only living muscle and connective tissue, nerves and blood vessels, tendons and bone and periosteum, if all of these structures have been exposed in the wound. In this stage of the operation, it may be necessary to manipulate the extremity, because not infrequently the wound extends around the bone or the bone may have been entirely lifted up from its bed and foreign bodies may have lodged behind it. The entire wound should be inspected. If muscles or tendons or nerves have been cut or severed, and their ends have been macerated or grossly contaminated, the ends should be excised with a sharp knife at this stage, care being taken to sacrifice no more of the structure than is necessary to insure removal of devitalized or contaminated tissue.

Treatment of Bone.—In some cases the fragments of the bone are grossly contaminated; that is, the bone may have been forced out of the wound and driven into the dirt. In such cases the bone cannot be cleaned, as dirt and other foreign materials have been forced into the bone spaces. This is particularly true of cancellous bone; grossly contaminated portions of the bone should be excised with heavy bone-cutting forceps or rongeurs and no attempt should be made to scrub them until clean. Loose fragments of bone which have been completely detached from their periosteal attachments and are devoid of circulation should, as a rule, be removed. Occasionally, they may be left for support or to prevent a loss of substance which will necessitate shortening of the extremity. However, as a rule, it is advisable to remove them because, if they are left, they usually will act as inert foreign bodies and, even though infection may not occur, they will do relatively little, if any, good. This is particularly true of fragments which include the entire thickness of the cortex as such fragments show little tendency to unite; they do

developed in fascial spaces. This is done in order to insure that when the drug goes into solution in the fluid which will collect in the wound, all parts of the wound will be exposed to a saturated solution of the drug which is used. The amount of the drug used varies directly with the size of the wound. In most instances, from 5 to 10 gm. is sufficient, but 15 or 20 gm. can be used without causing symptoms of toxemia.

When implanted in a wound the drug is dissolved in the fluid which collects in the wound, and it is then absorbed and excreted. It does not appreciably interfere with the healing of the wound unless it is present in sufficient amount to form aggregates which are slowly absorbed and act as foreign bodies which keep the surfaces of the wound apart.

The sulfonamide drugs inhibit the growth of susceptible bacteria, and do not interfere with the normal defensive mechanism of the body. Thus, in a case of compound fracture in which débridement has been used, they prevent those bacteria which may have been left in the wound from multiplying, and the bacteria can be destroyed by the phagocytes. Of the two drugs in general use, sulfanilamide is effective against streptococci and is the more soluble. Sulfathiazole is more effective against staphylococci and the organisms which cause gas gangrene, and because of its relatively slight solubility will remain in the wound longer (probably more than forty-eight hours). I prefer a mixture of equal parts of sulfanilamide and sulfathiazole. Sulfadiazine can be used, but it is expensive and is not known to have any advantage over sulfathiazole when the drug is implanted in a wound.

The drugs can be sterilized by autoclaving, but if the sterile powder is not available I do not hesitate to implant the unsterilized powder in the wound.

Closure of Wound.—The question now arises as to whether or not the wound should be closed. Many surgeons believe that all compound fractures should be left open and that the limb should be immobilized and the wound permitted to heal by granulation. I believe that whenever possible the wound should be closed. If débridement has been adequate, most of the compound fractures encountered in civil life can be closed, provided operation is performed within the first eight hours, and many of them can be closed within the first twelve or twenty-four hours after the injury. Not only the time which has elapsed since the injury, but also the amount and character of the contamination, the amount of damage to soft tissues, and the mechanical conditions in the wound must be con-

If the bones are fairly stable, no internal fixation is advisable. If the fracture is a long, oblique one, or if it is a comminuted fracture, it may be advisable to use some internal fixation. In certain instances of oblique fracture, it may be advisable to reshape the ends of the fragments in order that they will be stable when placed in end-to-end contact.

In the past, I have avoided the use of internal fixation whenever possible. However, in recent years, with the use of vitallium and stainless steel, both of which are nonirritating, and also with the use of sulfonamide drugs, which help to lessen the tendency to the development of infection, it has been possible to use internal fixation in treatment of compound fractures with relative safety. Consequently, if plates, screws, or wires are indicated to hold the fragments together, there is no reason why they should not be used and applied at this stage of the procedure. They will render the after-treatment much more simple and will tend to make it more successful. If internal fixation is used, it should be applied according to good mechanical principles, and plates, wires, and screws should serve the purpose for which they are placed in the bone. If internal fixation is not used, an assistant should hold the limb after the fracture has been reduced and is stable, being careful not to move the fragments and thus cause them to be displaced while the wound is being closed.

In certain instances, especially in cases of comminuted or double fractures of the leg, one-pin or two-pin fixation may be more advisable than internal fixation or traction. At this stage of the operation, the pins or wires may be driven or drilled through the proximal and distal fragments, if the operative field is extensive enough to permit this procedure without breaking the aseptic technic. The pins or wires are to be placed well away from the fracture wound.

If a sufficient portion of the limb is not exposed in the operative field to permit this, the pins or wires can be placed after the wound has been closed or packed open. They should be incorporated in the cast which will immobilize the fragments.

Final Inspection of Wound and Control of Hemorrhage.—If a tourniquet has been used, it is now removed. The wound is carefully inspected for bleeding points of any consequence and if any are found they are clamped, care being taken to include no excess tissue in the clamp. They are then ligated with fine silk or catgut.

Chemotherapy of Wound.—Either *sulfanilamide, sulfathiazole,* or a mixture of the two drugs in powder form is now sprinkled over the surface of the wound, care being taken to place some of the drug in the depth of the wound and in pockets which may have been

After-Treatment

The after-treatment includes chemotherapy, supportive treatment, if indicated, leaving the wound and the fracture alone, watching the patient for evidence of infection, and opening the wound and treating the infection if it occurs.

Chemotherapy.—As soon as the patient has recovered sufficiently from the anesthesia he should be given *sulfathiazole* or *sulfadiazine* in full doses (1 gm. by mouth every four hours). This should be continued for from four to seven days; that is, until the danger of infection is past.

Supportive Treatment.—The patient may need transfusions or intravenous administration of fluids; these should be given as indicated.

Leaving the Wound Alone.—The wound should not be dressed or the fracture disturbed for three or four, or more, weeks, unless there is some reason for doing so. Sutures may be left in for four weeks or more, or even until the fracture has united. If the wound is packed open, the cast may be changed or a window cut in the cast at the end of three or four weeks and the vaseline gauze removed and fresh vaseline gauze placed in the wound. Then the cast is reapplied.

Evidence of Infection.—As a rule, the first evidence of infection is pain; with the development of gas gangrene, this may be excruciating. The pain is accompanied by an elevation of the temperature and a disproportionate increase in the pulse rate. The toes or fingers may become swollen and cyanotic. The leukocyte count is elevated and the wounds are red, hot and edematous.

Treatment of Infection.—If infection supervenes, the wound should be opened widely, provided it has been sutured, or the vaseline gauze should be removed if the wound has been treated by the open method, and thorough drainage assured. Immobilization and chemotherapy should be continued. Also, supportive treatment should be intensified as indicated. If gas gangrene is present, this should be treated as indicated in Chapter XII, and this treatment should dominate the picture.

sidered in determining whether the wound should be closed or packed open.

In military surgery under war conditions, débridement should be employed in most cases of compound fracture; the wound should be sprinkled liberally with sulfanilamide or sulfathiazole powder, and packed open with vaseline gauze. A dry dressing should then be applied and the fracture immobilized in a plaster-of-paris cast or splint. This is because the surgeon who sutures the wound should watch the patient until the danger of infection is past, and under conditions of war this may not be possible.

In closing the wound no attempt is made to close it in layers as buried sutures are avoided when possible. The skin and underlying fat or superficial fascia are sutured in one layer with a continuous suture of silkworm gut, deknatel, or some other nonabsorbent material. Tension is avoided and, if necessary, tension incisions are made on either side of the wound in order to effect satisfactory closure. Care is taken not to draw the sutures too tightly, and the wound is closed without drainage. Sulfanilamide or sulfathiazole powder is then sprinkled over the sutured wound and a dry dressing is applied.

If, because of the lapse of too much time since the injury or for any other reason, it is deemed inadvisable to close the wound, interrupted sutures of silkworm gut may be placed in the wound to be tied a few days later, or the wound may be partially closed, or it may be packed loosely with vaseline gauze and covered with a dry dressing, the sulfonamide powder having been placed in the wound as described previously.

Immobilization.—The fracture has been reduced before the wound was closed and the fragments must now be immobilized by external fixation. This is true whether or not internal fixation was used, and whether or not the wound was closed. The immobilization is necessary not only for the treatment of the fracture, but also because it is one of the most important measures in combating infection. The fragments can be immobilized in splints with or without traction or in a plaster-of-paris cast which may or may not be padded. I use a plaster cast and usually use very little padding. It is important that the cast be applied while satisfactory position of the fragments is maintained, and that it include the joints above and below the fracture. If the fragments are not stable when reduced, I do not hesitate to transfix each end of the bone with a stainless steel pin or wire, and to incorporate this in the cast in order to maintain length of the limb, or a pin or wire in the distal fragment may be used and traction applied.

CHAPTER XII

TREATMENT OF INFECTED COMPOUND FRACTURES

FRACTURES which are compounded from without, and which are seen twelve hours or more after the injury, may be considered infected; consequently, the surgeon must attempt to evaluate the gravity of the infection and regulate his treatment accordingly. The degree of infection varies directly with the virulence of the infecting organisms, with the length of time that has elapsed since the accident, and with the amount of damage to the soft tissues in the vicinity of the wound. The first consideration is to determine whether or not gas gangrene is present, or imminent, and whether or not severe pyogenic infection is present, or imminent.

In cases in which there is severe damage to the soft parts with relatively little drainage through the skin even without infection, there will be marked swelling of the limb and discoloration of the subcutaneous tissues. A glance at the wound will usually disclose serum or even frank pus; and a smear made from this material, when stained and examined, usually will reveal bacteria, either staphylococci or streptococci or a number of different organisms. One should be particularly impressed by the presence of large, short, thick bacilli in the exudate from the wound as these are likely to be the organisms which cause gas gangrene. On the other hand, they may be relatively harmless saprophytes.

DIAGNOSIS OF GAS GANGRENE

The diagnosis of gas gangrene is not a simple matter in its early stages, as in any case of compound fracture the presence of saprophytic organisms and devitalized tissues may give rise to a foul or even fecal odor. Likewise, the severe pain, rapid pulse, moderate elevation in temperature, and general appearance of an extremely ill patient, may result from infection with staphylococci or streptococci as well as from gas gangrene.

Gas gangrene should be suspected, of course, when the wound has a foul odor, when dark pus exudes from it, when the surrounding

immediately after the diagnosis has been made, then to proceed as soon as possible with the surgical treatment, and repeat the dose of antitoxin after the operation until the patient reacts favorably or dies. The usual initial dose is from 10,000 to 20,000 units given intravenously or intramuscularly, and this is repeated at intervals of six hours until 100,000 units have been given or the patient reacts favorably or dies. At the surgeon's discretion, administration in the divided doses and at the intervals described may be continued beyond a total of 100,000 units, until the desired effect is gained or the patient dies. Sulfathiazole should be given in full doses and a blood transfusion should be given when indicated.

Surgical Treatment

The surgical treatment consists of wide incision, and excision of all infected and devitalized tissue. In cases of massive gas gangrene, amputation may be necessary; and this should be high enough to include all infected and devitalized tissues. Too often, amputation is done at the site of election in the leg for gas gangrene of the foot and ankle, and the extremity is later reamputated in the thigh only to have the patient die of the infection. On the other hand, the surgeon should not sacrifice a knee and upper half of the leg needlessly. In other words, he should, if possible, determine how high the gangrene has extended, and should save as much of the extremity as possible; but his first consideration should be the life of the patient.

In certain instances in which the infection is localized in the wound, or in the subcutaneous tissues, wide incision and local excision and drainage, after sprinkling *sulfathiazole* powder in the wound, are sufficient surgical measures. More often, muscle will be involved, and the devitalized muscle is brownish in color, and does not bleed when cut, or contract when pinched with forceps. Such muscles should be exposed generously by longitudinal incision, combined with transverse incisions in the deep fascia, and widely excised, leaving only healthy, red, bleeding, contractile muscle; the wound should be sprinkled generously with sulfathiazole powder, left wide open and packed lightly with dry gauze. At times, it is necessary to remove entire groups of muscles, such as the anterior tibial and the extensor muscles of the toes. After operation, *sulfathiazole* is administered in full doses, polyvalent *gas-gangrene antitoxin* is given, and the patient is watched closely for the appearance of the infection in other parts of the extremity.

If the main blood vessels of the extremity are hopelessly damaged, or if massive gangrene involves the distal portion of the extremity,

skin is tense or marble-like in appearance and copper colored, when the pulse rate rises disproportionately to the increase in temperature, and when the patient appears unusually ill and has an icteric color. If smears of the pus contain short, thick bacilli in large numbers, the diagnosis should be considered sufficiently established to warrant surgical intervention for gas gangrene. The crucial point in the diagnosis, however, is the presence of gas in the wound or tissues, or both, and if this is carefully looked for it usually can be detected. It should be remembered, however, that gas may be present in the wound or tissues without gas gangrene. This is due to the physical characteristics of some wounds, into which outside air is drawn and becomes pocketed in dead spaces between the fragments or in the tissues. Also, occasionally in cases of injury of the thorax, air that has escaped from the lungs and through a pneumothorax may be found in the tissues. The presence of air or gas in the tissue can be determined by palpation if a fine crackling crepitus can be obtained. When much lies between muscle planes, it also can be identified in the roentgenogram, but the diagnosis usually can be made before enough gas is present to be visible in the roentgenogram.

In a case of compound fracture in which gas gangrene is present, if the region around the wound is gently palpated, a few small gas bubbles can be pressed out. This may also occur if the fragments are gently moved to change pressure inside the wound. The gas will have a faintly fetid odor; not necessarily a foul fecal odor.

If the surgeon is uncertain about the presence of gas in the wound, the limb should be immobilized, and the wound covered with a dressing and left for an hour. The surgeon should then return, reexamine the wound by gentle palpation and, if necessary, by manipulation. In the presence of gas gangrene, more gas will have accumulated in the wound during the interval and it will be possible to express it and confirm the diagnosis. Cultures should be made, but surgical intervention should not be delayed.

TREATMENT OF GAS GANGRENE

The patient should be given full doses of the polyvalent gas-gangrene antitoxin which is now on the market. This will not, of course, save the patient's life unless proper surgical treatment is carried out, and should not be depended on to do so. It should always be used, because it apparently does no harm, and may make the difference in the patient's resistance between survival and death after the operation. It is my practice to give a full dose of the antitoxin

immediately after the diagnosis has been made, then to proceed as soon as possible with the surgical treatment, and repeat the dose of antitoxin after the operation until the patient reacts favorably or dies. The usual initial dose is from 10,000 to 20,000 units given intravenously or intramuscularly, and this is repeated at intervals of six hours until 100,000 units have been given or the patient reacts favorably or dies. At the surgeon's discretion, administration in the divided doses and at the intervals described may be continued beyond a total of 100,000 units, until the desired effect is gained or the patient dies. Sulfathiazole should be given in full doses and a blood transfusion should be given when indicated.

Surgical Treatment

The surgical treatment consists of wide incision, and excision of all infected and devitalized tissue. In cases of massive gas gangrene, amputation may be necessary; and this should be high enough to include all infected and devitalized tissues. Too often, amputation is done at the site of election in the leg for gas gangrene of the foot and ankle, and the extremity is later reamputated in the thigh only to have the patient die of the infection. On the other hand, the surgeon should not sacrifice a knee and upper half of the leg needlessly. In other words, he should, if possible, determine how high the gangrene has extended, and should save as much of the extremity as possible; but his first consideration should be the life of the patient.

In certain instances in which the infection is localized in the wound, or in the subcutaneous tissues, wide incision and local excision and drainage, after sprinkling *sulfathiazole* powder in the wound, are sufficient surgical measures. More often, muscle will be involved, and the devitalized muscle is brownish in color, and does not bleed when cut, or contract when pinched with forceps. Such muscles should be exposed generously by longitudinal incision, combined with transverse incisions in the deep fascia, and widely excised, leaving only healthy, red, bleeding, contractile muscle; the wound should be sprinkled generously with sulfathiazole powder, left wide open and packed lightly with dry gauze. At times, it is necessary to remove entire groups of muscles, such as the anterior tibial and the extensor muscles of the toes. After operation, *sulfathiazole* is administered in full doses, polyvalent *gas-gangrene antitoxin* is given, and the patient is watched closely for the appearance of the infection in other parts of the extremity.

If the main blood vessels of the extremity are hopelessly damaged, or if massive gangrene involves the distal portion of the extremity,

amputation is necessary. The circular or guillotine type of amputation is usually advised. It is to be noted that the guillotine amputation is not a straight transverse section of the limb, but that soft tissues and bone are so divided that the end of the stump forms an inverted cone, or shallow funnel, when traction is made on the skin.

In performing the guillotine amputation, the skin and subcutaneous tissues are divided by a circular incision around the limb, and permitted to retract. The deep fascia is then divided on a line with the proximal margin of the skin, and permitted to retract. The superficial muscles are then divided on a line with the retracted fascia, and the deep muscles are divided at the level to which the superficial muscles have retracted. The bone is divided at the point to which the deep muscles have retracted. Thus the stump without traction presents a plane surface, and offers free drainage of all intermuscular spaces.

After hemostasis has been secured, the stump is sprinkled liberally with sulfonamide powder, and a dry gauze dressing is applied. Strips of adhesive tape are then fixed to the skin, and the patient is placed in bed and traction applied to the stump. This traction converts the end of the stump into an inverted cone, and causes it to heal in a few weeks with a relatively small scar on the end. By immobilizing the stump and the tissues, the traction aids in combating any infection which may be present in the stump. When the operation is properly performed, and the stump is properly treated afterward, it is the ideal amputation for infected limbs in war, and reamputation is rarely necessary.

It is now recognized that most of the infection is in the muscles, and that the subcutaneous tissues are not extensively involved. Consequently, I use the usual anterior and posterior flaps of skin and subcutaneous tissue, but excise the muscle well above the level where it is devitalized. If, when the distal portion of the limb is removed and hemostasis is obtained, it is found that certain muscles in the stump are involved by the infection, the stump may be incised longitudinally, and these muscles excised at a higher level if this is indicated. The stump is sprinkled generously with sulfathiazole powder and is packed lightly with dry gauze and bandaged loosely. The skin flaps may be tacked together over the gauze with a few sutures.

If the infection continues up the limb, wide incision of the stump with excision of involved muscle or reamputation at a higher level is indicated.

Roentgen Therapy

A good deal has been written about the roentgen-ray treatment of gas gangrene, but this is based on clinical observations and is not supported by experimental evidence. I do not know whether it is of value, but I see no objection to using the deep roentgen therapy as adjuvant treatment provided the surgical treatment, chemotherapy, and administration of antitoxin are carried out as described previously, and provided the patient can be given the treatment without subjecting him to a great deal of pain. A portable roentgen-ray machine is advisable and the advised dose of roentgen rays is small (100 roentgens twice a day for two or three days).

TREATMENT OF INFECTED COMPOUND FRACTURES NOT COMPLICATED BY GAS GANGRENE

In these fractures the bacteria have begun to invade the tissues, and from six to twenty-four hours or more have elapsed since the injury. The infection is usually mixed and, in addition to staphylococci and streptococci, various saprophytic bacteria may be present. The infection may be relatively mild, or it may be rapidly progressing or fulminating. The general condition of the patient may be good, or he may be moribund. If his general condition is not good, this may be due to the severity of his injuries or to the infection.

It is evident, therefore, that such fractures present problems similar to those considered in the treatment of compound fractures, plus those directly due to the infection, and that clinical judgment is even more important than surgical skill in their treatment.

If shock from the injury dominates the picture, supportive treatment of the patient is the first consideration, and this may include transfusion of blood and rest. If toxicity from the infection is the most important feature, this demands intensive chemotherapy, adequate drainage, and immobilization of the infected tissues.

The treatment is carried out along the lines described previously except that, in the presence of an acute fulminating infection, chemotherapy is started immediately, and it is advisable to administer sulfathiazole (2 to 4 gm. of sodium sulfathiazole) or sodium sulfadiazine intravenously in order that an adequate concentration of the drug in the blood may be obtained as quickly as possible. Débridement should be replaced by drainage, and even this may not be necessary as the wound may be wide open and drainage may be adequate. Local chemotherapy is useful, but is not effective against bac-

teria which have deeply invaded the tissues. Immobilization must not be neglected, because this is one of the most effective measures in combating the infection. The limb and the patient should be moved as little as possible.

The Operation

If the wound is obviously infected, operation is for drainage and is not for débridement. The wound is enlarged in the long axis of the limb, and the deep fascia is cut transversely, if necessary, in order to expose the depths of the wound. Bleeding vessels are clamped and ligated with fine catgut. Foreign bodies and loose pieces of bone are removed. Necrotic tissues are excised, but no effort is made to excise the walls of the wound. The wound may be flushed with physiologic salt solution, or wiped with gauze. The fracture is then reduced, but no device for internal fixation is applied. No attempt is made to repair muscles, tendons or nerves. After the wound is dry, it is sprinkled liberally with sulfathiazole, or with a mixture of sulfanilamide and sulfathiazole, is packed loosely with vaseline gauze, and a dry dressing is placed over the wound.

The fracture is then immobilized in a plaster-of-paris cast and, if transfixion pins or wires are necessary for maintenance of correct position of the fragments, these may be used, but they are placed as far from the infected region as possible.

In a borderline case, in which the wound is not obviously infected, débridement may be carried out, as described in the preceding chapter, if the general condition of the patient permits, but the wound is not closed. It is sprinkled liberally with the sulfonamide powder, packed open and immobilized in a cast.

After-Treatment.—For chemotherapy, 1 gm. of *sulfathiazole* or *sulfadiazine* is administered by mouth every four hours until the infection is well controlled. Supportive treatment and rest are used as indicated.

The wound is not inspected or dressed until the odor of the discharge from the wound renders change of the cast advisable, unless there is evidence of continued invasion of the tissues by the infection. This is indicated by pain, fever, increased pulse rate, toxemia and progressive anemia.

At each change of plaster, the skin around the wound is smeared with zinc-oxide ointment in order to combat scalding and local infection of the skin, and sulfonamide powder is implanted in the wound.

TREATMENT OF OLD, INFECTED, COMPOUND FRACTURES

Old, infected, compound fractures are those in which osteomyelitis has occurred. This differs from the ordinary hematogenous osteomyelitis, however, in that the infection in the bone tends to be limited to the vicinity of the fracture. The treatment of these fractures is usually surgical, but it is important that the operation be done at the proper time, and that it be so planned as to remove all infected bone, and to result in union in good functional position. When union is present, it is advisable not to interrupt the continuity of the bone if possible, because the presence of a fresh fracture not only greatly complicates the after-treatment, but may result in nonunion. For this reason, I do not believe in subperiosteal resection in the treatment of these fractures. This is especially true in the case of adults as the power of osteogenesis is considerably less than it is among children.

As a rule, these patients are ready for a definite surgical attempt to eliminate the infected bone in from three to six months after the injury, whether or not sequestration of dead bone has occurred. In some instances, the dead bone will have undergone sequestration and simple removal of the sequestra will result in permanent healing of the infected wound. In other cases, and these are in the majority, whether or not sequestra are present, there will be a variable amount of infected and dead bone enclosed in the callus, and it will be necessary to perform an operation such as ordinarily is used in an attempt to cure osteomyelitis. That is, the bone is approached by a long longitudinal incision between muscle planes, care being taken to avoid important blood vessels and nerves. The bone is exposed subperiosteally, and a wide saucer-shaped region is excised by beginning with what, in the surgeon's judgment, will be sufficient to remove all of the infected bone. This saucerization is continued upward and downward on the shaft until all of the infected region is removed. The wound is then packed open with vaseline gauze, and a plaster cast is applied according to the Orr method.

In the operation on the bone I usually remove about one half of the entire cortex, leaving the continuity of bone intact; I also make the walls of the cavity smooth and sloping, and remove, as far as possible, all overhanging edges. The wound is then sprinkled generously with sulfathiazole powder, packed with gauze that is well impregnated with vaseline and the wound is left open. A gauze dressing is then applied, the limb is wrapped with sheet cotton, and a plaster

cast is applied. This cast is left on for from three to six weeks and the material which drains from the wound is allowed to accumulate in the dressing beneath the plaster. At the end of this time the plaster is removed. The vaseline gauze will have been partly pushed out by the healing of the underlying tissue. The wound is simply wiped, and the limb is washed with soap and water, and then thoroughly washed with alcohol. The wound is again sprinkled with sulfathiazole powder, repacked with vaseline gauze, and another plaster cast is applied. This cast is left on as long as possible, and is removed only when the odor becomes extremely unpleasant, or secretions cause the cast to soften. If necessary, a third or fourth cast is applied in the same manner. If the operation is successful, that is, if all of the infected bone has been removed, the wound may be expected to heal by granulation from the bottom, and to remain healed.

This method, which is known as the Orr method, has an advantage over the Carrel-Dakin method, as used formerly, in that the patient can be placed in a cast and sent home, the painful dressing is eliminated, the after-treatment is greatly simplified, and the results probably are better. The principal objection to the Orr method is the odor. This is lessened by implanting one of the sulfonamide drugs at each dressing.

Chemotherapeutic Method

An even more satisfactory technic is one described by Drs. Frank Dickson and Rex Diveley. It has proved successful in a high percentage of cases in which it has been tried. The technic is as follows:

Two days before the operation, the oral administration of sulfathiazole or sulfadiazine is started. Either drug is administered in doses of 1 gm. every four to six hours.

The skin of the operative field is prepared as for a clean surgical operation.

The walls of the sinus tract and wound are excised back to healthy tissue, care being taken to remove all infected granulation tissue.

Sequestra are removed.

The cavity in the bone is saucerized, or the ends excised if nonunion is present. The object is to remove all necrotic or infected bone.

Hemostasis is obtained, and the wound inspected for any infected tissue.

The entire surface of the wound is sprinkled with sulfathiazole powder.

The wound is closed without drainage. I use a deep skin suture of silkworm gut and avoid the use of buried sutures.

The limb is immobilized in a plaster-of-paris cast.

The oral administration of sulfathiazole or sulfadiazine is continued for from five to seven days after the operation.

On several occasions I have used this technic in cases of old, ununited, infected, compound fractures, and within one or two months have reopened the wound, placed a large onlay bone graft across the fracture, and have fixed it with metal screws. The ends of the fragments were drilled, and bone chips and cancellous bone were placed around the line of fracture. The entire wound was then sprinkled with sulfathiazole and closed. Healing occurred by primary intention, and union has occurred in those cases in which sufficient time has elapsed.

This technic is suitable for chronic infections, but not for acute infection, or for chronic infection in which there is an acute exacerbation.

CHAPTER XIII

GUNSHOT FRACTURES

GUNSHOT fractures are compound fractures caused by force from without. The wounds are either penetrating or perforating, and are all potentially infected. For this reason, many of the wounds demand operation and débridement. Experience has shown, however, that gunshot wounds, when inflicted by high velocity bullets fired from rifles or pistols, can be treated expectantly just as can compound fractures which are compounded from within, because the high velocity sterilizes the bullet and it does not carry clothing or other foreign material into the wound. In cases in which the wounds are penetrating, the bullet tends to remain in the tissues as an inert foreign body, and should be let alone. I practically never probe for or operate to remove a bullet. In cases of gunshot wounds in which operation is necessary, the operation is performed to prevent or combat infection, and not to remove a now harmless bullet. Fractures from shrapnel, shell fragments, hand grenades, and so forth are caused by projectiles which are low in velocity, and some are irregular in shape and are larger than are the high velocity bullets. In cases in which compound fractures are caused by such projectiles, operation should be performed immediately and débridement should be employed, just as it is in the presence of grossly contaminated compound fractures.

If the gunshot wound is a penetrating one, it should be laid open by a large, longitudinal incision which should extend to the depth of the wound. If the wound is a perforating one, a longitudinal incision should be made on each side of the limb. The track of the missile is lined by devitalized tissue, which must be excised by sharp dissection. It should be remembered that the track may be irregular because of the contraction of muscles after the infliction of the wound. Foreign bodies are removed, and fragments of bone are treated, just as in cases of other compound injuries, the viable fragments being left *in situ*. The wound may be left open or may be closed, depending on the time which has elapsed since the injury, just as in the case of other compound fractures.

Bullet wounds may be simple, perforating wounds of the bone, as are those caused by high velocity bullets, or they may result in *relatively simple fractures if they are caused by spent bullets.* Again, the bones may be extensively shattered, the fragments being driven far into the tissues and the bullet broken into fragments which are also scattered through the tissues. The bullets should not be probed for, since the bullet itself usually can be tolerated by the tissues. *The wound should be left either entirely alone and the fracture* treated as a simple fracture after the wounds in the skin have been painted with tincture of iodine and dressed with dry sterile dressing, or the wound should be widely opened and adequate débridement performed.

A special type of injury in civil life is a compound fracture caused by a shotgun fired at close range. This injury produces a large, gaping wound, shot are scattered widely through the tissues, there is a great deal of destruction of the soft tissues, and it is not unusual that some of the wadding from shotgun shells is carried into the wound *and buried in the tissues. This* wadding *may contain* spores of tetanus, or of organisms which produce gas gangrene. In such cases thorough débridement must be performed and the patient should be given tetanus antitoxin (unless toxoid has been given) and gas-gangrene antitoxin and treated with sulfathiazole.

CHAPTER XIV

TREATMENT OF COMPOUND FRACTURES AND ACCOMPANYING WOUNDS AS MODIFIED BY WAR CONDITIONS

WHETHER compound fractures are encountered in civil life or in war, basically they are the same and the same basic principles obtain. Much of the preceding chapters has been occupied by this fundamental material. It now remains to consider how war changes conditions.

The treatment of such fractures must be modified on account of several factors, among which are the following: (1) There are the difficulties in transportation which may increase the time between the inception of the wound and the surgical treatment. (2) Large numbers of wounds may have to be handled by relatively few men in a relatively short time. (3) It may be necessary for the surgeon to work with a reduced armamentarium because of the demands of mobility and the possible failure of supplies. (4) Surgical technic must be simplified and speeded up or streamlined. A meticulous, time consuming operation may be admirable in civil life, but is a monkey wrench in the machinery of an evacuation hospital during a push. (5) Usually, wounds must be packed open and the limbs immobilized, because the patient will be evacuated as soon as he is ready to travel and the surgeon cannot watch the patient for evidence of infection.

In this chapter I shall consider briefly the treatment of the wounded man from the time the wound is received until he has received his final treatment. I shall not attempt to follow any prescribed military plan, but shall merely consider first aid in the field, the treatment at the field dressing station* or regimental aid post, the treatment in the field hospital and the treatment in the base hospital. What is said of the soldier in battle is also true of civilians who are injured in the bombing of cities.

* It is realized that military installations are widely modified in various situations and that terms by which they are designated change from time to time and with the service concerned.

FIRST-AID TREATMENT

It is assumed that each soldier will carry with him a first-aid dressing and that, in addition to a dressing and bandage, this will contain about 5 gm. of sulfanilamide or sulfathiazole or, preferably, a mixture of the two drugs. When a man is wounded, if he is close to his dressing station and can get there under his own power, he naturally will go to the dressing station without preliminary treatment. However, if he has suffered a severe wound and is not able to get to the dressing station he must be picked up and carried there and probably will have to remain in the field for some time before he is picked up. It is now recognized that it is poor economy to send stretcher bearers and surgeons into an assault with advancing troops. They must follow the troops and wait until there is a lull in the battle; or it may be necessary to collect the wounded during the night. In a war of movement many of the wounded soldiers will be left behind and this is true whether the Army is advancing or retreating. Consequently, first-aid dressings should be applied after the sulfonamide powder has been poured into the wound. It is also advisable, if the soldier has been supplied with tablets of sulfathiazole or sulfanilamide, that he swallow 2 gm. of the drug immediately.*

If a man has suffered a compound fracture of the femur or of the bones of the leg, it is advisable that splints be applied in the field. This is especially true if he has to be carried for a very long distance to the first-aid station. It is also advisable that all soldiers who have sustained fractures of the lower extremities or wounds of the abdomen and thorax be moved on stretchers.

When the injured soldier has arrived at the first-aid station a rough estimate of the severity of the wound is made. The dressing is examined and, if necessary, more sulfonamide powder is poured into the wound and a dry dressing is applied. If hemorrhage is sufficient to be of consequence, it is stopped by means of pressure bandages, if possible, or by a tourniquet, if this is necessary. The patient should be kept warm and dry and given a hot drink. He also should be given morphine and tetanus toxoid, if he has been immunized with this preparation; otherwise, tetanus antitoxin should be administered

As has been stated before, all personnel of the Army is immunized actively against tetanus by vaccination with tetanus toxoid (plain). The initial series of injections is given as soon as possible after each individual enters the service. It consists of three subcutaneous injec-

* The sulfonamide drug supplied and doses recommended may be modified as experience is gained

tions of the toxoid at intervals of three to four weeks, each injection being 1 cc. in amount. A stimulating dose of 1 cc. normally will be given at the end of the first year only. However, if an individual is to depart for a theater of operations he is given a stimulating dose of 1 cc. unless such departure is within a period of six months subsequent to the stimulating dose given at the end of the first year. The record of tetanus vaccinations is stamped on the identification tags of the individual. Immunity lasts from six months to five years. Untoward reactions are rare. An emergency stimulating dose of 1 cc. of tetanus toxoid is administered to any previously vaccinated individual who incurs a battle wound or burn, or any nonbattle injury which is likely to be complicated by tetanus, or who is to undergo a secondary operation for which the surgeon deems tetanus toxoid advisable.

All personnel of the Navy is also immunized actively against tetanus, but the system differs in the following respects from that employed in the Army: (1) alum precipitated toxoid is employed instead of plain toxoid; (2) each dose is 0.5 cc. instead of 1 cc.; (3) the initial series consists of two injections at intervals of four to eight weeks, and (4) a stimulating dose of 0.5 cc. is given at the end of one year or if the individual is wounded.

All fractures of the long bones and wounds of the joints are splinted, if possible before the patient is put in an ambulance and sent back to the field hospital or its equivalent. If the patient is in a state of surgical shock or of impending shock, and if he is seriously injured, every effort should be made to get him back to the field hospital or to some other point where the shock can be treated with as little delay as possible.

This does not mean that the principle that a patient in shock should not be transported until he has reacted from the shock should be violated if this can be avoided. If the patient's systolic blood pressure is less than 100 mm. of mercury, it can be assumed that he is in shock or shock is impending; if possible, this shock should be treated at the field dressing station and he should not be transported until he has reacted from the shock. On the other hand, if it is not possible to treat the shock at the field dressing station and if transportation is available, the patient should be given a full dose of morphine and transported to a point where the shock can be treated. This is done with the knowledge that in some cases corpses instead of patients will be delivered by the ambulance. On the other hand, such patients would certainly have died if left without treatment and the lives of those who survive the journey may be saved.

However, patients in shock should be treated for shock before being transported and the earlier the treatment is instituted the better the prognosis. At the field dressing station or its equivalent the rules which should be followed are: (1) Give morphine. (2) Stop hemorrhage and splint fractures of the extremities. (3) Put the patient on a stretcher, cover him with blankets and apply heat externally with a primus stove. (4) Give warm, stimulating, sweetened drinks (coffee, tea or cocoa). (5) Give transfusions of plasma if possible.

As soon as the patient reacts from the shock he should be sent back to the field hospital.

TREATMENT AT FIELD HOSPITAL OR EQUIVALENT

On arrival at the field hospital the patient is subjected to a brief examination and is classified, and the subsequent treatment is outlined. It is the duty of the examining physician to decide whether or not the patient is in a condition of shock, whether or not he is fit for operative treatment and whether or not this is indicated. Slightly wounded patients may be treated in the dressing station or may not need immediate treatment, this having been administered at the field dressing station. If the patient is in a state of severe shock, he should not be sent to the operating room immediately, but he should be given appropriate treatment for shock, as noted in preceding chapters, and, if indicated, he should then be taken to the operating room as soon as he has reacted sufficiently from the shock to permit operative treatment.

It is to be noted that soldiers wounded in battle may be exhausted mentally and physically, and may be debilitated by cold and exposure before they are wounded. Consequently, shock is more likely to be present than in a group of similar patients in civil life. In addition, there is another type of shock caused by the blast of high explosives and this must be looked for, especially among bomb casualties.

Likewise, virulent infections are more likely to be present in the wounds of soldiers in battle because they may not have had an opportunity to bathe for some time and their clothes may be dirty. This is especially true of wounds of the lower extremity and buttocks

This sorting out of the wounded (*triage*) requires considerable surgical judgment and should not be entrusted to an inexperienced medical officer as the decisions made in the receiving room at a time when large numbers of wounded soldiers are being brought to a

field hospital may make considerable difference not only in the mortality rate but also in the effectiveness of the surgical teams working in the hospital. In addition to determining the general condition of the patient and whether or not operative treatment or treatment of shock is indicated or necessary, the surgeon also should check for the presence of a tourniquet and determine how long it has been on, and he should determine whether or not the patient has had a stimulating dose of tetanus toxoid since he was wounded. If this has not been administered it should be administered. If the patient never has been immunized with tetanus toxoid, tetanus antitoxin should be given according to the plan detailed elsewhere. If the patients are suitable for operation they are then sent directly to the operating room as fast as the operating room can take care of them or, they are sent to the roentgenographic room where roentgenography or roentgenoscopy is performed to determine the presence of foreign bodies and fractures. If such are present, their position is noted on the skin in two planes and the patients are then sent directly to the operating room. Care is taken to move a severely injured patient as little as possible and the splints and dressings are not removed until the patient is on the operating table and usually not until he is under anesthesia.

Anesthesia

This will depend a good deal on the choice of the surgeon in charge of the particular hospital. In the past, ether has been the most generally used anesthetic agent. However, it is possible that in war intravenous anesthesia with pentothal sodium or some similar preparation will be used widely. Not only can this be transported easily, but in the hands of one skilled in its use it is relatively safe. Also, when it is used considerable time can be saved between operations, as the patient goes to sleep almost instantly and awakens very quickly after administration of the anesthetic agent is stopped.

Surgical Treatment

On the operating table the dressings applied at the field dressing station are removed and a decision is made as to what treatment is necessary. Certain wounds caused by high velocity bullets, such as machine gun bullets and rifle bullets, as a rule, do not require débridement. The margins of such wounds should be excised under local or general anesthesia after the skin has been painted with a cutaneous antiseptic substance. Sulfonamide powder should be implanted in the wound, which should be covered with vaseline gauze

and a dry dressing. The fracture, if present, should be reduced and immobilized just as though it were a simple fracture.

On the other hand, large wounds caused by shell fragments, bombs, hand grenades and other projectiles which are traveling at relatively slow speed, and which consist of large or irregular fragments, are nearly always infected, as the fragments carry infectious material with them into the tissues. These irregular missiles frequently damage the tissues widely and sometimes carry a portion of the patient's clothing into the tissues. All such wounds demand débridement or incision and drainage, depending on whether they are in the contaminated or infected stage. The presence or absence of missiles in the tissues and the condition of the bone will have been determined and noted at the roentgenologic examination and this knowledge will have been conveyed to the operating surgeon so that he has a rough idea of what he will encounter.

What has been said about the necessity of débridement or drainage of all wounds due to shell or bomb fragments must be modified because many of the modern air bombs break into small fragments which travel at high velocity and cause wounds similar to those of rifle or machine gun bullets. These wounds do not require débridement.

In case of multiple wounds, the number of wounds may be so great that débridement or even superficial excision of all wounds is not practicable. This is especially true in cases in which the patient has been sprayed with small fragments from a high explosive bomb. In such a case many small foreign bodies may be present. These foreign bodies probably will do no harm and no attempt should be made to remove those which are buried in the tissues. Common sense should be the guide in treating multiple injuries and the surgeon should consider the patient as a whole rather than concentrate his attention on one or two specific injuries.

Preparation of the Skin.—Either scrubbing with soap and water followed by alcohol and ether and a cutaneous antiseptic preparation (one of the mercurial tinctures, such as merthiolate, mercresin, or metaphen, or weak tincture of iodine) or the dry method of painting the antiseptic substance on the unwashed skin, either with or without shaving, may be used. In times of stress, when large numbers of wounded soldiers are to be treated, it is obvious that the wet method, which is time consuming, will not be used. The limbs will not be shaved but simply will be painted thoroughly with whatever cutaneous antiseptic substance is at hand and is being used in that particular hospital.

Débridement.—The limb is then straightened and draped, and traction is made to steady it. The edges of the skin are excised; usually not more than ¼ inch (0.6 cm.) of the skin around the margins of the wound is removed. If the skin adjacent to the wound is burned deeply, this charred portion is excised. If there is a wound of entry and a wound of exit, the edges of the skin of both wounds are excised at this stage. Usually, the wound of exit will be larger than the wound of entry. The knife and forceps used in excising the edges of the skin are then discarded.

Enlargement and Exploration of Wound.—It is nearly always necessary to enlarge the wound in order that its depth may be adequately explored. For this reason, incisions are made at its upper and lower borders in the long axis of the limb and these are extended as far as is necessary to permit examination of the deep structures. The primary incision for enlargement of the wound extends through the skin and the superficial and deep fascia to the muscle. Blood vessels of consequence are clamped where they are encountered, but only the large vessels are tied off, usually with number 0 plain catgut or finer catgut if this is available. The edges of the wound are now retracted gently, the traumatized and devitalized margins of the subcutaneous tissue and fascia around the wound are excised. These structures are then retracted and the deep fascia is incised transversely to expose the underlying muscles. Any foreign bodies encountered are removed as they are seen. The devitalized margins of the muscles, which are more or less macerated and discolored, are excised until only healthy muscle is left in the wound. Muscle which does not bleed or which does not retract when pinched is excised with a sharp knife or with scissors. If necessary, the enlargement of the wound through the fascia is carried down through the muscle in order to explore the depths of the wound and to determine the condition of the bone but, when possible, this is done through intermuscular planes.

Treatment of Bone.—Fragments of bone which are completely detached, or so nearly detached from the surrounding soft tissue that their blood supply appears to be inadequate, are removed. Large fragments which have a periosteal attachment and blood supply deemed sufficient to keep the bone viable are usually left *in situ* because it is important to avoid complete loss of continuity of the bone if this can be preserved with safety. The ends of the bone which are grossly soiled are excised with rongeurs or bone-cutting forceps. The ends of the bone are then lifted and further search is made for foreign bodies. Any devitalized tissue found in the depths

of the wound is excised. It is desirable to remove all foreign bodies but it is not absolutely necessary, and the surgeon should not devote a great deal of time to searching for small foreign bodies which may be buried in the tissues adjacent to the wound. Likewise, he should not extend the wound widely through healthy tissue in order to remove a missile which may have fractured the bone and then may have traveled some distance through healthy tissue before coming to rest. The important thing is to excise devitalized tissues, remove foreign bodies from the wound proper and pack the wound open. This was true in the last world war and is even more true today when strong re-inforcements in the form of sulfonamides are available against infection.

The wound of entrance is now enlarged slightly and this, too, is explored, but not to the extent that the larger wound of exit is explored. Its margins are excised and fascial and muscle walls are excised in order that as little devitalized tissue may be left as possible. If a tourniquet has been used it is now removed. The wound is now dried as thoroughly as possible. The hemostats are removed and bleeding points which persist are tied with fine catgut. The wound is then sprinkled generously with one of the sulfonamides.

Chemotherapy.—The sulfonamide used may be either sulfathia*zole* or *sulfadiazine*, or sulfanilamide or a mixture of *sulfanilamide* and sulfathiazole. I prefer a mixture of equal parts of sulfanilamide and sulfathiazole. The sulfanilamide is more soluble, will be present in the wounds in higher concentration and should penetrate the surrounding tissues more deeply. Consequently, it should be more effective against streptococci. Sulfathiazole, on the other hand, will remain in the wound longer and is more effective against staphylo*cocci and the bacteria which cause gas gangrene.* The status of sulfadiazine, and its effect when implanted locally, have not yet been determined. However, it is even less soluble than is sulfathiazole. Any of these chemicals can be used in the wound. They will not interfere with the healing of the wound and the amount used will not be toxic to the patient or to the tissues. This is especially true in wounds which are left open and packed with vaseline gauze and from which a considerable portion of the implanted drug will be drained out with the secretions from the wound. In such wounds an excessive amount of the drug should be implanted. It is possible that gramicidin (derived from soil bacilli) or penicillin (from molds) may be effective when implanted locally in wounds. If so, when available, they can be used instead of, or in combination with, the sulfonamide drugs.

Treatment of Nerves, Blood Vessels, and Tendons.—If nerves, blood vessels and tendons have been severed by the bullet or projectile, or have been almost severed, the devitalized ends should be excised, care being taken not to remove any more tissue than is necessary. The severed ends may then be left to retract (this is the safer procedure from the standpoint of sepsis) or they may be brought together with one or two strands of fine, plain catgut. This may make subsequent repair easier or may make it unnecessary in the case of muscles and tendons; bringing together of the severed ends tends to contribute to the ultimate restoration of function of the extremity. Whether or not these tissues are brought together will depend on the judgment of the surgeon and on the condition of the wound. If the wound is relatively fresh and the tissues are in good condition, they can be brought together with impunity, especially if one of the sulfonamide compounds is implanted in the wound. On the other hand, if a wound is ten or twelve hours old, and contains considerable devitalized tissue, it is probably wiser not to attempt to repair any nerves, tendons or muscles.

Reduction of Fracture.—The fracture is now reduced, usually by direct traction and manipulation, and the ends of the bones are opposed under direct vision. In certain instances it may be advisable to reshape the ends of the fragments in order to make the reduction more stable. In many instances, however, the fracture will be comminuted and the ends of the bone will be oblique. In such instances stable reduction of the fragments will not be possible. The question arises as to whether or not one should use internal fixation.

In civilian life, internal fixation is advised if operation is performed for compound fractures before bacteria have invaded the tissues and if débridement has been adequate. The use of stainless steel or vitallium plates, screws and wires and the use of sulfonamide drugs render this relatively safe. In war injuries, on the other hand, internal fixation is not advised except under unusual conditions. However, it is permissible to transfix each fragment with a stainless steel pin or wire of sufficient length to project from the side of the limb for about 2 inches (5 cm.). This wire can be incorporated in the plaster-of-paris cast, will maintain length of the extremity and will aid in maintaining the position of the fragments. If it is decided that transfixion and immobilization by the two-pin method is to be used, this can be done at the same time. The pins or wires are drilled or driven through the bone well away from the wound or they can be thrust through other bones in the extremity if necesssary. If operation is being performed with the patient on a fracture table

or fracture machine, in which the limb is held by transfixion with pins and the fracture is reduced, these pins are incorporated in the plaster-of-paris cast.

After the pins are in place, the wound is again inspected, rendered dry and more sulfonamide powder is sprinkled in the wound if this is thought to be indicated. The wound is then packed relatively loosely with vaseline gauze; a dry, sterile dressing is placed over the wound and a plaster-of-paris cast is applied. This cast may be of the skin-tight variety or it may be applied over a moderate amount of cotton sheet wadding or other padding, depending on the choice of the surgeon. If the surgeon is skilled in using plaster of paris and can apply a skin-tight plaster cast with reasonable skill, this affords more complete immobilization. On the other hand, if he is not skillful in the use of this type of cast, the patient may suffer considerable discomfort from pressure, aside from the discomfort incident to his wound, and it is advisable to use some padding. It is important to remember that the cast should immobilize the joints above and below the injury; that is, in a case of fracture of the ankle, the knee joint should be immobilized and, in a case in which the fracture involves the knee joint or thigh, the patient should be immobilized in a single plaster-of-paris spica cast, which grips the pelvis and extends to the toes of the injured extremity.

It is advisable to draw a rough outline of the fracture and to note the date of the operation on the damp cast.

Treatment of Wounds of Joints.—If the wound involves a joint, this should be opened widely at the time of the incision of the skin and fascia and the joint should be thoroughly explored. Loose fragments of bone and any foreign material present in the joint should be removed. Any soiled bone exposed in the wound should be excised. The joint may or may not be irrigated with physiologic salt solution, depending on the choice of the surgeon. In most instances it is possible to clean the joint adequately without irrigation. The wound should then be dried, the joint cavity should be sprinkled liberally with one of the sulfonamide drugs and the wound should be treated as has been described in the case of fractures not involving joints. The vaseline gauze packing should extend down to the joint cavity. In most instances the synovial membrane can be closed with fine catgut. In wounds which are not very recent, or which are in questionable condition, the joint should be left open. As a rule, no attempt should be made to suture the capsule or ligaments exposed in the wounds and severed. The joint should be immobilized in a plaster-of-paris cast as described previously.

Treatment of Wounds in Which Infection Is Present.—In the preceding paragraphs wounds which have not been definitely infected were considered. These wounds may be five or six hours old or they may be fifteen, twenty or more hours old. The presence or absence of infection in such wounds depends on the general condition of the patient, the nature and severity of the wound, the type of organisms which were implanted in the wound at the time of the injury and whether or not one of the sulfonamide compounds was placed in the wound shortly after the injury, as well as on the elapsed time.

Whether or not the wound is infected can be determined by the surgeon when he examines the wound after the dressing has been removed. If the tissues are red, hot and edematous, and if pus is present in the wound, there is no question but that infection is present. In such instances, and in instances in which the wound is not relatively clean, the operation is not one of débridement, but the treatment is drainage followed by chemotherapy and immobilization. Unless they are necrotic or burned, the edges of the wound are not excised after the skin has been painted with a cutaneous antiseptic substance, as described in preceding paragraphs. The wound is enlarged in the long axis of the limb by incisions through the fascia; the deep fascia is cut transversely and the depths of the wound are gently explored. All visible foreign material is removed. Obviously necrotic tissue is excised, but no attempt is made to remove all damaged or infected tissue. Deep pockets of the wound are opened. The granulating margins or walls of the wound are not excised, as these are nature's attempt to form a barrier against the spread of the infection. Loose particles of bone are removed and the wound is then sprinkled generously with one of the sulfonamide compounds and packed loosely with vaseline gauze. The skin around the wound is covered with vaseline gauze or zinc oxide ointment because the purulent discharge from the wound will tend to macerate the skin and cause blistering and burning pain. A rather voluminous dressing is placed over the vaseline packing and the limb is then encased in a plaster-of-paris cast, which usually is applied over padding. Transfixion pins and fixation incorporated in the cast may or may not be used. If the pins can be placed in parts of the limb not involved by the infection they can be driven or drilled through the bone without danger of spreading the infection, and the added immobilization which they afford more than compensates for the slight increase in this danger. If the main blood vessels of the limb are occluded or destroyed, amputation is necessary.

TREATMENT AT BASE HOSPITAL OR EQUIVALENT

Most patients will be evacuated to the base hospital before the original plaster cast which was placed on the limb at the time of débridement and reduction of the fracture has been removed. Under favorable conditions, the patients should be kept in the evacuation hospital until the danger of a spreading infection is over and it is relatively safe to send them back to the base hospital. The time involved will vary with the seriousness of the wound, the general condition of the patient, whether or not the wound was infected before the operation, and with the virulence of the infection. On the other hand, military necessity may demand immediate evacuation and the patient may reach the base hospital a day or so after operation.

In the great majority of instances in which the wound has been operated on while it was in a state of contamination rather than infection, the convalescence will be uninterrupted. The pain will not be excessive, the patient will not have more than two degrees of fever and his general condition will continue to improve rather than deteriorate. The presence of infection is suggested by an increase in temperature, increase in the pulse rate and, above all, by a throbbing pain in the limb. When this occurs, it calls for inspection of the tissues around the wound. This entails the cutting of a large window in the cast or removal of the cast. If the tissues are found to be tense, red and tender, it is advisable to remove the packing and to explore the wound. It may be necessary to provide more adequate drainage or in certain instances in which there is a fulminating infection it may be necessary to operate for gas gangrene or to amputate, as noted in a preceding chapter on the treatment of gas gangrene.

At the base hospital, the original dressing and plaster-of-paris cast are not disturbed until about three weeks or longer after the operation, unless there is some reason for doing so. It is to be noted that inspection of the wound exposes the wound to contamination with virulent bacteria and to the danger of a loss of the reduced position of the fragments. It is now believed that secondary or cross infection of wounds in the wards of military hospitals is an important cause of the prolonged disability which is very frequent in cases of compound fracture. Usually, the reason for the early application of a new cast is because the cast is soiled and has a bad odor This is especially true in the case of wounds which were infected. Wounds which are not infected tend to heal slowly beneath the vaseline gauze dressing, without much discharge or odor.

At the end of three weeks, or at about that time, the original

dressing should be removed and, as a rule, in the case of fractures, especially those treated with transfixion pins, this can be done through a window in the cast and will not necessitate a change of the cast which will disturb the position of the fragments. After the window has been cut in the cast, the dressing and vaseline gauze are removed and the surface of the wound is wiped gently with a dry sponge. It is then sprinkled liberally with sulfonamide powder, packed with vaseline gauze and covered with a dry dressing. This is bound firmly to the leg, either with or without replacement of the window. The local pressure tends to prevent local edema with bulging of the tissues through the window in the plaster and aids, rather than interferes with, healing. This dressing is repeated at weekly, or longer, intervals when indicated until the wound is healed. The cast is changed when necessary.

The subsequent course in the base hospital does not differ greatly from that in civilian life, except that soldiers are not worried about hospital bills and time lost from work.



SECTION IV

OSTEOMYELITIS

J. Albert Key, M.D.

SECTION IV

OSTEOMYELITIS

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AUTHOR'S PREFACE TO SECTION IV*

THE term "osteomyelitis" indicates inflammation of a bone which has been produced by a pyogenic organism. The inflammation may be acute, subacute, or chronic. It may remain localized and involve only a small portion of the bone, or it may spread at a variable rate to involve the entire bone. In certain instances the disease may spread by direct extension or by means of the blood stream to involve other bones and tissues or to produce abscesses in other portions of the body. The disease may be relatively mild and healing spontaneous, or it may be very severe and pursue a rapidly fatal course. There are all variations between the two extremes. As the infection spreads through the bone it involves all of the elements, including the bone marrow, cortex, cancellous portion, and periosteum.

In this section the typical acute and chronic osteomyelitis of long bones is considered in detail. Certain specific types of pyogenic infection of bone are considered rather briefly. The infectious granulomas of bone, such as syphilis, tuberculosis, and actinomycosis, are not considered. Excluded also from consideration are those chronic diseases of obscure cause which are still classified as being inflammatory lesions, such as Legg-Calvé-Perthes' disease, Osgood-Schlatter's disease, and other types of apophysitis or chronic epiphysitis or osteitis deformans (Paget's disease). Certain cysts of bone, concerning which there is as yet no definite evidence that the condition is the result of an infection by a pyogenic organism, also are omitted. Moreover, infection of the mastoid process, which is really osteomyelitis due to extension of the disease from the ear, is not considered in this section.

J. ALBERT KEY, M.D.

* It so happens that shortly after Dr. Bennett asked me to contribute the section on osteomyelitis to this manual I completed a chapter on this subject for Lewis' Practice of Surgery, and that chapter contained about all that I knew on the subject. Mr. L. W. Manners, President of the W. F. Prior Company, Inc., has very generously given me permission to use as much of that chapter as I wished to incorporate in this manual. I have used practically all of it and have made certain changes in order to make the material more suitable for a military manual. I have retained the extensive consideration of acute hematogenous osteomyelitis, which might almost be classed as a disease of childhood and is rarely seen among adults, because this is the foundation on which knowledge of pyogenic infections in bone rests.

CHAPTER XV

ACUTE HEMATOGENOUS OSTEOMYELITIS

THIS heading must not be understood to be absolute in its limitation of the subject matter of this chapter. The chronic form of the disease will enter the discussion from time to time, especially when complications and prognosis are under consideration.

INCIDENCE

The disease is relatively infrequent. About 0.5 per cent of all patients who are admitted to general hospitals have this disease but in hospitals devoted to the care of crippled children it may affect 6 per cent or more of all patients who are admitted. It is primarily a disease of childhood and adolescence; in most cases the patients are between the ages of five and fourteen years. However, it may occur in infancy or among adults. It is believed that the presence of the epiphyseal line and active growth of bone predispose the bone to pyogenic infection. Osteomyelitis is about twice as frequent among boys as among girls. This is usually explained on the basis that boys are more subject to trauma than are girls and that trauma is a definite factor in the production of the disease. The disease is said to be more frequent among the poor, who are assumed to be unwashed, but in my experience it is not limited to patients in any walk of life and affects rich and poor alike. Occupation does not seem to have anything to do with its occurrence.

CAUSE

A staphylococcus is the offending organism in about 90 per cent of the cases. As a rule, this is a hemolytic staphylococcus aureus. The Staphylococcus albus is the pathogenic organism in a relatively small percentage of cases. The next most common organism found in the cultures in cases of osteomyelitis is a streptococcus and, in a certain percentage of cases, both staphylococci and streptococci are reported to have been obtained at the primary culture, although this does not seem reasonable in a hematogenous infection. It is probable

Predisposing Causes

In considering the question of predisposing causes of a disease such as hematogenous osteomyelitis, it is necessary to consider the infection in the bone as secondary to the entrance of the organism into the blood stream, probably from some focus of infection elsewhere in the body. Possibly the organisms may enter through the undamaged mucous membranes of the gastro-intestinal or respiratory tract or even through the skin. It is believed, however, that in most instances, at any rate, the organisms enter the blood stream from some focus of infection. In cases of staphylococcic infection, the most frequent focus is furunculosis or milder infection of the hair follicles, and it is probable that this is the original focus or point of entrance of the organisms in the majority of cases of osteomyelitis. Probably the most frequent primary focus in cases of streptococcic hematogenous osteomyelitis is an infection of the upper part of the respiratory tract. In 40 to 50 per cent of the cases of osteomyelitis among young children the cause is streptococci.

Other types of foci are minor infected wounds, blisters which have become infected, burns and the lesions of impetigo. Yet others are the pustules of chicken pox, smallpox or smallpox vaccination which have become secondarily infected. Among infants, a rather common source of infection in the first month of life is the umbilical cord. Rarely, the disease may follow the extraction of a tooth or a streptococcic infection of the middle ear.

However, definite foci which might serve as primary sources of infection can be demonstrated in only about 25 per cent of the cases. It is possible that in many of the remainder the primary focus is not large enough to cause symptoms. In still other cases the primary focus probably heals without leaving a clinically recognizable trace, before the organisms which invade the blood stream have time to localize in the bone, or before the disease in the bone progresses enough to cause symptoms.

In addition to the primary focus, there is to be considered a general lowering of the resistance of the patient which may produce and favor the development of infection in the bone. For this reason, any acute illness, such as influenza, tonsillitis, measles, or whooping cough, may be considered to be a predisposing cause of a pyogenic infection. Likewise, undernourished children are believed to have less resistance to pyogenic infections than well nourished children. Also, children who are dirty are believed to be more susceptible to infection of the skin than are children who are cleanly in their habits. Consequently, one would expect the disease to be more common

that the mixed cultures which are reported in various series of cases in the literature are due to the fact that the material for cultures was taken after the wound or abscess had been draining and that other organisms than the one primarily responsible for the disease were present. The next most common organism is the pneumococcus.

The following organisms were found in 697 cases reported in the literature: staphylococci in 623 cases, streptococci in thirty-five cases, pneumococci in eighteen cases, both staphylococci and streptococci in sixteen cases, Bacillus typhosus in four cases, and Bacillus influenzae in one case. This is quite different from the statistics of Wilensky[26, 27] who reported the presence of the following organisms in 147 cases of osteomyelitis observed at the Mount Sinai Hospital: staphylococci in eighty cases, streptococci in forty-five cases, other organisms in ten cases, and mixed cultures in twelve cases. However, since Wilensky's statistics are so at variance with those reported by other observers and with my own experience, I believe that one may be reasonably safe in assuming that the chances are more than 10 to 1 that in a case of acute hematogenous osteomyelitis in which the patient is more than two years of age the pathogenic organism is a staphylococcus and that it probably is a hemolytic Staphylococcus aureus.

As will be pointed out later when the treatment of this condition is considered, this is an important factor because at the present time effective chemotherapy is available for streptococcic and staphylococcic infections. Also certain immunologic agents are at hand for combating staphylococcic infections and these may be used even before the organism causing the disease has been determined. However, it is to be noted that among children less than two years of age infection of the bone by streptococci is relatively more frequent than it is among older children and adolescents. As a matter of fact, Green and Shannon, in a series of seventy-six cases of acute hematogenous osteomyelitis observed in a children's hospital, found streptococci in 63 per cent and staphylococci in only 30 per cent. In three cases the disease was due to pneumococci, and gonococci were isolated in one case.

In osteomyelitis due to direct implantation of the organisms in the bones, such as that associated with compound fractures and penetrating wounds, the infection is usually of the mixed type. In addition to the usual pyogenic organisms, the organisms of gas gangrene and putrefactive and saprophytic bacteria may be present. The same is true in old cases of chronic osteomyelitis in which the wound has been open and draining for a long time.

the cartilage has been eroded from part of the articular surface. An abscessed tooth may lead to infection of the jaw and, when the tooth is extracted, acute or chronic osteomyelitis may develop in and around the socket.

Infection by Implantation

The most frequent form of osteomyelitis, in which the organisms are implanted directly into the bone, is that which results from compound fractures. In these injuries, and especially in those in which the wound has been compounded from without, that is, by the fracturing force, it is safe to assume that pathogenic bacteria have been carried into the wound and that the wound is contaminated by such bacteria. Within eight to twelve hours after the wound has been inflicted, these bacteria have invaded the underlying tissues which have been damaged by the fracturing force, and have been transformed into a suitable culture medium, with relatively little resistance to infection. As the organisms invade this tissue of which the resistance is lowered, they multiply, and infection of the wound begins. This infection involves all of the surface of the wound; it extends into the bone and may extend into the marrow cavity of the bone.

Owing to the fact that these wounds are usually open and the marrow canal is open for drainage, the infection is not, as a rule, very acute in the bone and tends to remain more localized than does a similar infection which has reached the bone by the blood stream. Exceptions to this rule are wounds which have caused extensive damage to the soft tissues, and those which contain the organisms of gas gangrene. Prompt and adequate débridement and the removal of any foreign material which may have been carried into the wound will, in the majority of cases, prevent the development of osteomyelitis following compound fractures. Likewise, gunshot wounds, shell wounds and other types of war wounds which involve the bone may result in infection of the bone, even though the bone only be exposed. Usually, however, in such wounds the bone is broken or penetrated by the projectile and these wounds constitute special types of compound fractures.

Under conditions such as exist in war, compound fractures are especially likely to become infected for the following reasons: (1) The patient often is physically and mentally exhausted before he is wounded; (2) his skin and clothes are likely to be dirty; (3) his wounds may be multiple; (4) he may be exposed to cold and wet for hours before receiving surgical attention; (5) these con-

among the poor and unwashed and it is possible that this is true, although I know of no statistics which prove or refute this expectation.

Also it must be considered that there must be some local cause which tends to result in localization of the bacteria in the bone. The peculiarities of the structure of the bones is considered under pathology. However, it is believed that trauma is a definite factor in the cause of the disease. This belief is supported by the following facts: (1) The disease is about twice as common among boys as it is among girls; (2) it is relatively uncommon before the age of two years when trauma is relatively rare; (3) it increases in frequency up to the age of about ten years and then maintains its level until the age of about fourteen years, at which point the frequency of the disease gradually subsides until the time when the epiphyseal lines are closed; after this time acute hematogenous osteomyelitis is relatively rare.

It is believed that relatively mild injuries may cause minute lesions in the vicinity of the epiphyseal line and that these lesions may result in local points of lowered resistance. As a matter of fact, a history of preceding trauma can be obtained in about 25 per cent of the cases. In other instances there is no explanation of why the disease localizes in the bone, unless it is considered that the bone is peculiarly susceptible to staphylococcic infection; this, of course, admits that it is not known why, with the entire body available, the bacteria settle in, and cause disease of, a bone.

Direct Extension of Infection in Adjacent Tissues

This is a relatively rare cause of osteomyelitis, with the exception of disease of the mastoid cells, which is due to extension of infection from the middle ear. One of the most frequent types of osteomyelitis is that which involves the terminal phalanx of the finger secondary to infection in the pulp of the finger. Here, extension into the bone is relatively easy because the bone is enclosed in a water tight compartment and, as tension develops, the circulation is excluded and the infection may readily invade the phalanx. Infection of the olecranon or prepatellar bursa not infrequently leads to infection of the underlying bone. Likewise, from abscesses near the spinal column, the disease may extend to the adjacent vertebrae. Deep ulcers on the leg, foot or elsewhere, may invade the underlying bone but spreading osteomyelitis rarely is a result of the invasion. Frequently, primary pyogenic arthritis may invade the bone that enters into the composition of a joint. This is especially true of the hip and of other joints after

entered the blood stream, probably from some focus. The question immediately arises as to whether the osteomyelitis is the principal cause of the patient's illness, or whether it is merely a fortunate or an unfortunate incident in a case of generalized septicemia. There is evidence to support both views. It is my opinion that a patient does not have septicemia before osteomyelitis develops. I believe that a few casual, pathogenic organisms enter the blood stream and that usually these organisms are rendered harmless by the normal defense mechanism of the body. However, if they become localized in the bone and start to multiply and invade the bone, osteomyelitis develops.

In other words, although there were a few organisms in the patient's blood stream, he did not have clinical septicemia and the few organisms in the blood stream were not of clinical importance. It is probable that all persons from time to time have a few such organisms in their blood streams, and that these organisms are made harmless without the development of any local or general disease. At any rate, in cases of acute hematogenous osteomyelitis, these organisms settle in the bone and start to grow. Why they should settle in the bone and leave other organs untouched is at present unknown.

It is generally conceded that bone is especially vulnerable to staphylococci and streptococci. However, in what this vulnerability lies is not known. Fraser has connected it with the reticulo-endothelial cells, which he thinks are especially numerous in the bone. However, these cells are also very numerous in the spleen and liver. If it is assumed that the primary localization in the bone is in the metaphysis, near the epiphyseal line, the explanation of Hobo must be considered. After injecting India ink into animals, he found that large amounts of the ink collected in the reticulo-endothelial cells and in the wide capillary bed of the diaphysis adjacent to the epiphysis. The same was true of bacteria. If this finding is correlated with the fact that epiphyseal strains are especially likely to occur among growing children and adolescents, and that these strains may result in minute, asymptomatic hemorrhages in the diaphysis adjacent to the epiphyseal line, then a fairly rational explanation has been found of the development of osteomyelitis in this region.

If the factor of trauma is eliminated and the infection of the bone is attributed to stagnation of the blood stream in this region, the explanation falls down, because the blood stream flows just as slowly in some other parts of the body as it does in this portion of the metaphysis. The majority of observers are in agreement that the

ditions all predispose to loss of blood and to surgical shock which may be present and lower the general resistance to infection; (6) the patient must be transported to the hospital under unfavorable conditions; (7) in times of stress he must await his turn before receiving adequate surgical treatment; (8) after the operation he must be evacuated to another hospital; (9) instead of being treated by one surgeon he is treated by a succession of surgeons.

Clean, open operations on bones, especially if the operation has been unduly prolonged, so that the local resistance of the tissues has been lowered and the vitality decreased, occasionally may result in infection of bone with subsequent development of acute or chronic osteomyelitis. Likewise, amputations of infected limbs, through fields which may or may not be judged to be infected at the time, may lead to infection of the stump of the bone and the development of osteomyelitis. In cases in which foreign material, such as screws, nails and wires, is implanted in bones at the time of operation, it is generally believed that the incidence of postoperative infection is higher than it is in cases in which similar operations are performed without foreign material being left in the wound.

A type of infection of bone which is becoming increasingly common is that due to the piercing of the bone by a Kirschner wire or Steinmann pin for the application of sketetal traction in the treatment of fractures and deformities of the limbs. The increase is due to the fact that skeletal traction is being used more frequently than before, and reduction of fractures by use of machines is becoming more widely used. It is probable that, even with adequate sterilization of the skin and careful aseptic technic, pathogenic bacteria in sufficient numbers to cause infection occasionally will be carried into the bone. The better the technic, the less likely is this to occur. As a rule, the infection of bone around a Kirschner wire or Steinmann pin is relatively mild and clears up after the wire or pin has been removed, although occasionally the infection results in the formation of small ring sequestra where the pins pass through the bone. In some instances, also, the infection leads to acute, widespread, diffuse osteomyelitis which extends up and down the shaft of the bone just as though it had been implanted in the marrow cavity by way of the blood stream.

PATHOLOGY

As a preliminary to the development of acute hematogenous osteomyelitis, it must be assumed that the infecting organisms have

most frequent primary localization of the disease in the bone is in the metaphysis near the epiphyseal line (Fig. 57). By animal experiments, as well as clinically, I have found that staphylococci, if they cause a lesion at all, are likely to cause it near the epiphyseal line. However, in experiments in which I attempted to produce osteomyelitis as it is seen clinically, the staphylococci which were injected into the blood stream either killed the animal promptly or resulted in small abscesses, *many of which were beneath the periosteum*, adjacent to the epiphysis, while others appeared in the cancellous bone of the metaphysis. The severe, diffuse, spreading infection of bone, with toxemia and often septicemia and death, which is seen clinically, did not occur.

The site of the primary lesion has been called the fixation point and, although most observers believe that it is in the metaphysis, others do not agree. For instance, Wilensky noted the approximate order of frequency of the fixation points as (1) the periosteal vascular plexus; (2) the superficial haversian canals in the cortex of the bone; (3) the metaphysis; (4) the main trunk of the nutrient artery; (5) the minor branches of the nutrient artery, and (6) the main branch of the nutrient artery.

After the organisms have escaped the defense mechanism of the body and have become arrested at their fixation point, whatever part of the bone it may be, and have begun to multiply, there develops in the bone a small abscess. This abscess is similar to an abscess or furuncle in the soft tissues, except that, because it develops in a compartment with rigid walls, it is likely to develop at a more rapid rate, to spread more extensively, and to cause more severe general toxemia than does a similar abscess of soft tissues.

As the bacteria begin to multiply at the fixation point, they invade the adjacent tissue, and they liberate exotoxins which diffuse into the surrounding tissue. These toxins cause death of the cells with which they come in contact. They also cause hemolysis of erythrocytes, coagulation of plasma, death of leukocytes and, if they reach the circulation in sufficient amounts, they cause the death of the patient. In addition to these changes thrombosis also occurs. As the tissues of the host begin to react to the infection the local circulation is slowed, the smaller blood vessels are dilated, and leukocytes and mononuclear cells collect in the vicinity and attempt to form a barrier around the bacterial focus. The leukocytes phagocytose a variable number of the cocci. However, these leukocytes which are in the center of the inflammatory mass are soon killed by the toxins and liberate proteolytic ferments which tend to cause

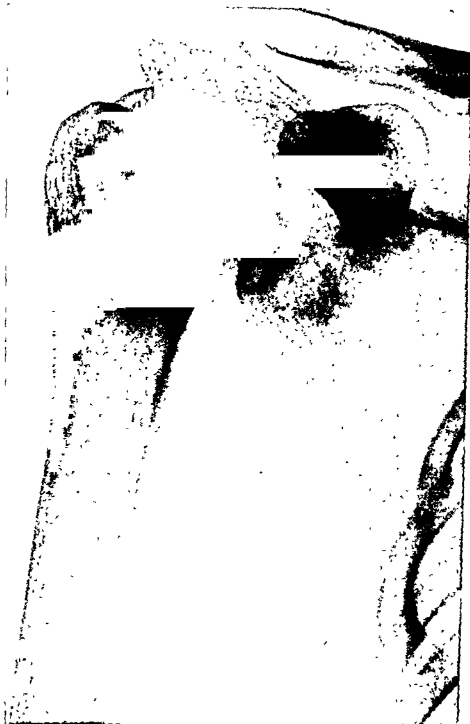


Fig. 57.—Acute osteomyelitis of the proximal end of the humerus; slight rarefaction at base of trochanter. Duration, one week (Key in Lewis: Practice of Surgery. W. F. Prior Co, Inc).

the cortex is relatively thin, the periosteum is elevated by a collection of fluid beneath it. This fluid steadily increases in amount and, as the bacteria invade the fluid, it becomes purulent and the pressure of the abscess strips up the periosteum along the shaft of the bone. Its extension is blocked on the epiphyseal side because the periosteum is firmly attached at the epiphyseal line.

There is thus formed a subperiosteal abscess which arises at the point where the infection passes outward through the shaft of the bone, through the nutrient canals, and spreads out beneath the periosteum, stripping it up from the bone in all directions. However, if the infection begins in the metaphysis the spread is toward the shaft and it may extend the entire length of the shaft, up to the epiphyseal line at the other end of the bone. It may extend, also, entirely around the bone, thus completely isolating the shaft of the bone from the rest of the body, causing it to be entirely surrounded by pus except at the two ends where it is attached to the epiphyseal cartilages. Thus, there is a progressive shutting off of the supply of blood to the involved bone and this results in a variable amount of necrosis. However, it is believed that most of the necrosis which results from pyogenic infection of bone is not due to the ischemia which has been produced by the shutting off of blood, but is an actual killing of the tissues by the toxins that are liberated by the staphylococci.

During this period when the infection is spreading, and when there is inadequate walling off of the infection and separation of it from the tissues of the host, there is considerable danger that the bacteria may enter the blood stream in increasing numbers. The mechanism by which they enter the blood stream is not known. It is probable that a considerable amount of the bacteremia is due to the spread of the bacteria through thrombi in blood vessels, because pyogenic bacteria are characterized by their ability to invade thrombi and living tissues. It is probable, also, that some of the bacteria are carried into the blood vessels by phagocytic cells and thus enter the blood stream and are liberated as the cells are killed. It is evident that not all cells which phagocytose bacteria kill the bacteria; sometimes the bacteria get the upper hand and the cells are killed. It is possible also that bacteria may spread by a tumor-like growth directly through the walls of otherwise intact sinusoids and blood vessels. Finally, the continued growth of the bacteria in the closed cavity of the bone generates pressure which tends to force infected thrombi out through the nutrient canals; it is argued that the trauma of operative opening of the bone tends to dislodge such thrombi

autolysis of the dead tissue. Thus, pus is formed. The fixed connective tissue cells which are not killed tend to proliferate in an attempt to form a wall around the focus of infection. Also, the smaller blood vessels in the region are dilated and, in the periphery of this inflammatory wall, there is a collection of small round cells or lymphocytes.

The pathologic change is similar to the development of a furuncle in the soft tissues or in any other portion of the body. In the bone, however, the process must proceed under certain difficulties because the cells which react against the infection are enclosed in a bony compartment which has nonelastic walls. Consequently, it is believed that the thrombosis of blood vessels is more widespread and that there is less ability on the part of the defense cells of the organism to wander into the inflammatory region and prevent infection. It is also believed that there is less ability on the part of the fixed connective tissue cells to proliferate and form a fibrous wall to shut off the infection from the rest of the body. The rigid portion of the bone can play no part in the defense against infection. It can only remain static and, when toxins of sufficient intensity permeate its substance, the cells in the bone lacunae die. The same is true of the osteoblasts which cover the surface of the trabeculae, line the canals of the bone and cover the surface of the bone beneath the periosteum.

With continued proliferation of bacteria, and continued necrosis of tissue with which they are in contact, there is a gradual increase in size of the inflammatory process or abscess. The process spreads from within outward and in all directions, but follows the lines of least resistance. For instance, if the infection begins in the metaphysis near the epiphyseal line its spread across the epiphyseal line into the epiphysis is blocked by the cartilaginous plate which is relatively impermeable to the infection. Consequently, it spreads outward through the cancellous bone. When it reaches the subcortical zone it spreads through the cortex and appears beneath the periosteum, the infection passing through the haversian or nutrient canals, carrying before it a region of inflammation, with dilatation of blood vessels and extravasation of fluid into the tissues. When it appears beneath the periosteum, symptoms begin to arise locally, because the periosteum has a rich nerve supply. While the infection is limited to the interior of the bone the patient feels no pain and in the beginning has no general symptoms, apparently because, during this period, the focus is relatively small. After the cortex has become perforated, and in the diaphyseal region near the epiphyseal line

infection may reach the medullary canal by direct extension through the cancellous tissue of the metaphysis, traveling in a longitudinal direction. It is also possible that the infection may even begin in the medullary canal, or occasionally beneath the periosteum, and may extend up and down the bone beneath the periosteum and then enter both the diaphysis and the metaphysis by means of the nutrient



Fig. 58.—Roentgenograms made in the same case as that represented in Fig. 57, but three weeks later. Infection has extended downward and involved the elbow joint. Slight production of new bone and rarefaction of the shaft (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

canals. Occasionally, both metaphyses of the bone are involved and the intervening diaphysis is free from the disease. This may be the result of two simultaneous or nearly simultaneous foci developing in the bone, but it is more likely the result of a migration of the infection along the shaft from one metaphysis to the other, without involvement of the intervening shaft.

What is it that limits the spread of the disease in the bone?

and cause a shower of bacteria to enter the blood stream. At any rate, a pyogenic infection in bone is more likely to cause bacteremia than is a similar infection in the soft tissues.

After the subperiosteal abscess has formed, the infection breaks through the periosteum. The infection either ruptures the periosteum from pressure or, more likely, by causing necrosis and extending through the periosteum. The process is similar to that which takes place in other tissues but the periosteum offers a more firm barrier than do ordinary soft tissues. Then the abscess continues to enlarge, following the path of least resistance, until it becomes subcutaneous. It gradually erodes its way through the skin and its contents are evacuated when the skin is ruptured. A sinus is then formed and drains for a variable period.

This is the natural course of the disease if the patient survives the infection without treatment, and if the infection is sufficiently virulent to cause an abscess which, in turn, causes necrosis of the bone, perforates the periosteum and continues to migrate through the tissues until it erodes through the skin and discharges spontaneously. Death of the patient, however, may intervene. Usually this is due to overwhelming toxemia, or to an overwhelming number of organisms finding their way into the blood stream. Assuming that the patient survives, the course may be modified by increased resistance on the part of the patient or by relatively low virulence on the part of the organism. In either instance the infection may remain in the bone and may become walled off as a chronic focus of infection in the bone, in which case the infection ceases to spread and may remain indefinitely, being surrounded by a wall of chronic inflammatory tissue and later by eburnated bone. In cases of relatively mild infection the disease may disappear completely, the bone may return to an apparently normal condition and the patient may suffer no ill effects as a result of the infection.

In a considerable number of cases the infection reaches the medullary canal of the bone and involves the fatty bone marrow, causing necrosis of this marrow and frequently of a variable amount of the cortex of the shaft of the bone. Starr[24, 25] expressed the opinion that, as a rule, the abscess begins in the metaphysis near the epiphyseal line, extends through the thin cortex of this region, strips up the periosteum and then extends back into the bone and reaches the medullary canal by means of the haversian canals and nutrient foramina which perforate the shaft of the bone. Whether or not this is the usual form of extension of osteomyelitis in the long bones of children, I do not know. It is probable that in some instances the

host is increased to a point at which the local disease is walled off and cannot penetrate further into the bone.

As was stated previously, in its spread the infection follows the path of least resistance and the abscess generates a certain amount of pressure. The amount of the pressure is not known. However, while the infection is confined within the bone, it is probable that



Fig 60.—Roentgenograms made in the same case as that represented in Fig. 59. The elbow is ankylosed but the infection in the bone is still active. The roentgenogram on the left was made one month, and the one on the right was made two and a half years after the onset of the disease (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

considerable pressure is generated, and that the fluid contents of the abscess in the bone cause tension in the surrounding tissues. This results in a stripping up of the periosteum, unless it is perforated early in the course of the disease. This periosteal stripping is limited by the firm attachment of the periosteum around the metaphysis at the epiphyseal line. It is further, but less securely, limited by the

Presumably the disease continues to spread until an equilibrium has been reached between the virulence of the infection and the re-



Fig. 59.—Extensive destruction and formation of new bone. Roentgenograms made in same case as that represented in Fig 58, but nine months later (Key in Lewis: Practice of Surgery. W F. Prior Co, Inc.).

sistance of the host. This is a phenomenon which is as yet poorly understood. The disease either tends to burn itself out and the virulence of the bacteria becomes attenuated, or the resistance of the

compact and the cancellous bone is a cellular phenomenon and is not due to the bacteria or to the proteolytic ferment in the pus, and that the *absorption occurs only where this bone is in contact with* living, inflammatory tissue cells.

In cases of acute osteomyelitis the absorption *is first visible in* the roentgenogram about seven to ten days after the onset of the *disease. If the involvement is extensive,* the bone may have a worm-eaten appearance at this time. Mottling or regions of rarefaction may be scattered through the portion involved by the infection, and this may include the entire metaphysis. In cases in which the disease begins in the compact bone of the cortex, considerable time must elapse before the absorption has progressed to a point at which the bone is sufficiently rarefied so that the change can be detected roentgenographically. As evidence that dead bone is not absorbed unless it is in contact with living tissue, may be cited the fact that sequestra *may remain almost* unchanged in abscess cavities for a period of years. On the other hand, bone, part of which is killed and which is *surrounded by living bone, may be gradually absorbed and replaced* by living bone over a period of years and never be separated from the surrounding living bone. It is not unusual in cutting bone in cases of chronic osteomyelitis to find long strata of definitely dead bone with living bone on each side of them.

Necrosis of Bone

In cases of staphylococcic infection the bacteria liberate an exotoxin which has necrotizing properties and kills the tissues with which it comes in contact. It is probable that this necrotizing toxin is the principal factor in the death of the bone, although it is possible that occasionally considerable portions of bone may be deprived of their circulation by extension of the disease and, in such an instance, both the bone and the soft tissue in the interstices of the bone will die and will then be invaded by the infection. It is not known how long the toxins from the bacteria must remain in contact with the bone before it is killed. In many instances the surface of a bone may be bathed in pus for a considerable time and yet little or no necrosis may take place. At any rate, if necrosis occurs it is only surface necrosis and there may be *no sequestration,* or only a few small scales of bone may be loosened. In other instances, and especially when the infection surrounds *the bone, or at least* lies on both sides of it, as in a case in which there is an infection in the medullary canal and also an abscess *beneath* the periosteum, the entire thickness of the cortex may be killed for a variable dis-

attachments of muscles and ligaments. It is favored by gravity. In other words, the infection tends to spread down hill and, as a rule, the posterior or dependent portions of bones are more involved than are the superior portions or anterior portions, because the patient is usually lying on his back most of the time. In certain instances I have seen infection begin in the upper end of the humerus, extend down the humerus, involve the elbow joint (Figs. 58, 59, 60) and then extend down the bones of the forearm by direct extension.

During and after the acute phase of the disease, certain phenomena occur which should be mentioned, as they are integral parts of the process. Chief among these are absorption of bone, necrosis of bone, separation of sequestra, and production of new bone.

Absorption of Bone

The absorption of bone in the immediate vicinity of the inflammation begins shortly after the inflammation begins. This is accomplished by living cells and not by bacteria or their products, and it is probable that most of the absorption of bone which occurs in cases of acute osteomyelitis is absorption of living, and not of dead, bone. It is carried out by the osteoclasts and also by the connective tissue cells and by round cells; that is, cells of inflammatory tissues. Bone is not absorbed by phagocytosis. The absorption is probably a chemical phenomenon, the nature of which is as yet unknown.

Absorption of bone is at first largely limited to, or at least it is first visible in, the trabeculae of the cancellous bone. As the disease progresses and reaches the cortex, there are absorption of the cortex, and broadening of the haversian canals which perforate the cortex. As these canals are enlarged, and as the cortex is absorbed from within outward, it is perforated. The infection first makes its appearance through these canals, and eventually through an opening in the cortex. *Other things being equal, the mass and density of a given piece of bone determine its rate of absorption and whether or not it will be absorbed.* Slender trabeculae may disappear quickly while dense, cortical bone persists for a long time.

It is probable that this absorption continues as long as acute inflammation is present in the bone. It is also probable that there is some absorption of the dead bone. At any rate, there must occur a variable amount of necrosis of the cancellous bone. However, it is relatively rare that sequestra of cancellous bone are found in cases of chronic osteomyelitis. Consequently, most of the cancellous bone which is killed is absorbed. There is also some absorption of the compact bone. It is believed, however, that the absorption of both the

surrounded by living bone and there was no evidence of active disease in this region.

I know of no adequate comparative pathologic studies on acute osteomyelitis due to streptococci and on similar infections due to



Fig. 61—Severe osteomyelitis of the proximal end of the femur; involvement of the hip joint and sequestration of the head of the femur. The roentgenogram on the right, which was made six months after the one on the left, shows beginning absorption of the head of the femur (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

staphylococci. However, it is probable that the process caused by a streptococcic infection resembles that of a staphylococcic infection relatively closely, except that the streptococci probably spread through the tissues more widely and have a greater tendency to

tance; occasionally the entire diaphysis and the metaphysis at each end may be killed. As a rule, however, the sequestration and necrosis of bone are limited and involve a relatively small portion of the diaphysis.

Sequestration

After a portion of the bone has been killed it may form a sequestrum or may be absorbed (Fig. 61). Again, if it is surrounded by living bone, it may remain as a portion of the apparently intact bone for a variable time and eventually be replaced by living bone (Fig. 62). In a case in which there is massive necrosis of relatively dense bone, such as a considerable portion of the full thickness of the cortex, it is not unusual for this large mass of dead bone to be separated from the rest of the cortex and to form a sequestrum which lies loose in the tissues until it is extruded or removed. The exact manner in which this separation is accomplished is not known. It is probably due to an inflammatory reaction in the living bone adjacent to the dead bone, and it is probable that the separation is in large measure accomplished, not by absorption of dead bone, but by absorption of the living bone around it by the inflammatory tissue. If the necrosis is limited to cancellous bone it is relatively rare for sequestration to occur unless a considerable mass of cancellous bone is killed quickly. This occurs particularly in the calcaneus, where a fulminating infection may involve the entire bone within a relatively short period. In such instances massive necrosis of the cancellous interior of this bone may occur, and there is no opportunity for living granulation tissues to reach it and cause absorption.

In instances in which necrosis does not involve the entire thickness of the shaft, small, scalelike sequestra occasionally may be split off and lie loose in the tissues or be discharged. However, it is more usual for the dead bone to remain attached to the living bone, and to be covered by a layer of newly formed living bone; thus the dead bone becomes incorporated in, and remains a part of, the original bone which has now become thickened. I believe that this dead bone is gradually absorbed and replaced by living bone by the process known as "creeping replacement." It is my impression that I have found such dead bone incorporated in living bone, in operating in cases of chronic osteomyelitis in which periods of two or more years had intervened since the original infection, and in which there was no evidence that there had been a more recent extension of the disease, with killing of the cortical bone. The dead bone was present in the interior of the cortical bone as layers of lamellae which were

that there is considerable damage to, and even necrosis of, bone as a result of the streptococcic infection, but that it is not the massive necrosis which causes sequestration. Certainly, there is marked absorption of bone in streptococcic infections, and rarefaction of bone is seen in the early stages just as it is in staphylococcic infection.

Production of New Bone

It is characteristic of pyogenic infections (both streptococcic and staphylococcic) that they stimulate the production of new bone in regions of inflammation in which living cells are present. This production of new bone probably begins in the very acute stage of the disease and occurs in those regions in which living osteoblasts, with an adequate blood supply, are present adjacent to the infection. It is especially marked when the periosteum is stripped up. This stripping carries with it a considerable number of osteogenic cells, some of which are probably pulled off with the blood vessels and fibers of Sharpey which penetrate the cortex of the bone, while other osteogenic cells lie between the cortex and the fibrous layer of the periosteum. On the periosteal side there is a rich vascular network. Consequently, these cells have more resistance to the infection than have similar cells in the interior of the bone. As a result, they rapidly form new bone and, in from seven to ten days after the infection has reached the periosteum, sufficient new bone may have been formed to be visible in the roentgenogram or when the bone is exposed by operation.

In instances in which the periosteum is stripped over a wide region, this new bone forms a sheath around the old shaft. When a portion of the shaft is killed and separated as a sequestrum, the new bone which is formed around it is called the *involucrum.* The size of the involucrum varies directly with the extent of the periosteal stripping. It may involve and enclose the entire shaft or a section of the entire thickness of the shaft. Usually, however, only a portion of the circumference of the shaft is killed and undergoes sequestration, or there may be no visible sequestra, and the new subperiosteal bone fuses with the original shaft and causes the bone to be thickened in the involved region. In cases of prolonged infection, this thickening may be considerable and the bone may become much thicker and more dense than normal.

In addition to the involucrum, new bone is formed in both the marrow canal and the haversian canals. As a result of the formation of new bone, the marrow canal may be obliterated or the infected portion of the canal may become walled off by bulkheads of new

follow the lymphatic channels. Also, it is undoubtedly true that the streptococci do not produce such a potent necrotizing toxin as do staphylococci and, as a result, massive necrosis is not, as a rule, seen



Fig. 62 —Roentgenogram made in the same case as that represented in Fig 61, but seven years later. A new rudimentary head of the femur has formed but infection still is present in the shaft. When this roentgenogram was made, all of the wounds had healed and there were no clinical signs of activity of the infection (Key in Lewis: Practice of Surgery. W. F. Prior Co, Inc.).

in cases of streptococcic infection. Consequently, streptococcic infection of bone does not tend to be followed by sequestration. In fact, Robertson said that he never had seen sequestra formed after osteomyelitis caused by streptococci. On the other hand, it is probable

and then become active. There is, however, a fair chance that it may never have an opportunity to cause disease in the lifetime of the patient. The expression "once osteomyelitis, always osteomyelitis" contains a certain measure of truth. On the other hand, clinical experience has shown that in a very large percentage of cases of acute and chronic osteomyelitis an adequate surgical procedure has produced a permanent cure in spite of the fact that the operation has not been completely efficient because it has not removed all of the bone which could have been affected by the disease.

CLINICAL PICTURE

A patient with acute osteomyelitis is suffering from an acute infectious disease in which the focus of the infection is situated in the bone. Consequently, the symptoms are those due to the general toxemia which is caused by the products of the disease entering the circulation and also those due to the local inflammation. Since acute osteomyelitis is a disease which varies greatly in severity, the symptoms vary greatly in their intensity.

As the patient usually is a child, the history may have to be obtained from the parents and may not be very reliable. The onset may have been abrupt or may have been preceded by a prodromal period of from one to three days or more, during which the patient felt ill, suffered from loss of appetite, was listless and generally below par. There may or may not have been headache and a general aching sensation during this period. Inquiry into the past history may reveal that the patient has suffered from boils or infections of the skin, or has received an injury of sufficient severity to have been noted and regarded as a possible cause of the difficulty. On the other hand, the general symptoms may have begun abruptly. The condition may have been ushered in by a chill, followed by a high fever, general malaise, loss of appetite, severe aching, throbbing pain at the site of the local lesion, inability to use the affected part, and inability to rest. These symptoms may have progressed rapidly until the patient became comatose or entered a state of delirium.

In the usual case, the first symptom of the disease is pain and a sensation of stiffness in the affected extremity. As a result of this the patient lessens his activity and may remain in bed, or may be able merely to get about the house. As the pain increases, fever may be noted. The patient may or may not have a chill and may or may not feel hot. As the temperature increases, the patient becomes flushed in the face, the skin becomes hot and dry and the tongue coated. The urine becomes concentrated and the pain increases. With

bone which form at either end of the abscess cavity. In cancellous portions, still living trabeculae are thickened, and this bone gradually becomes more dense as the spaces between the trabeculae are encroached on or obliterated; eventually the bone which was formerly spongy may become eburnated.

Likewise, new bone is formed around the walls of the haversian canals in the cortex so that the lumens of these canals are gradually narrowed and eventually many of them are obliterated. This formation of new bone in the haversian canals results in considerable increase in the density of the bone so that it becomes eburnated, contains a minimum of organic constituents and is largely composed of the inorganic portion of the bone.

It is to be noted that this formation of new bone within and around the old bone results in both a thickening and an increase in density of the affected bone; the process may wall off regions of inflammation and in these regions living bacteria and low-grade inflammation of connective tissue may be present and may persist for many years. The infection in these walled off regions may remain dormant apparently indefinitely but it may flare up at any time and cause recurrence of the active disease. It is thus evident that in the removal of infection in bone it is not sufficient merely to remove the obviously involved portion. By this I mean the abscess and the walls of the abscess. If one expects to cure the disease permanently, it is necessary to remove all of that portion of bone which is sclerosed or which has reacted to the infection by the production of new bone. This would mean that a considerable portion of the shaft of the bone would have to be resected, as the amount resected would have to extend up to a point where normal bone was encountered. Obviously, this is, as a rule, impracticable. Consequently, most operations for the cure of chronic osteomyelitis are incomplete. This is one reason that there is such a definite tendency for the disease to recur, even though the operation may have been followed by healing. On the other hand, in a considerable percentage of cases, although a variable amount of sclerotic and potentially infected bone is left after a saucerization operation, the wound may heal and the patient may live a normal life and may never have a recurrence of the disease.

It is not known how long the pathogenic organisms may remain dormant. Experience indicates that the period may extend over many years. It cannot be foretold in a given case how great a number of organisms or how large an amount of the diseased tissue may be walled off in the sclerotic bone and remain dormant for a period

pain becomes more marked. By examining other parts of the limb and returning to the original site of tenderness, it can be determined that the tenderness is rather sharply localized. The tenderness is usually present by the time the fever, pain and disability develop. Occasionally, in cases in which tenderness is indefinite, percussion of the bone may elicit pain.

As the disease progresses, the involved region becomes swollen, owing to edema in the soft tissues over the bone. This swelling is followed by local warmth and redness and eventually fluctuation may develop owing to accumulation of fluid, first beneath the periosteum and, after the periosteum has ruptured, owing to the formation of an abscess in the soft tissues. As a rule, however, unless the bone is very superficial, fluctuation cannot be detected until the periosteum has ruptured and until an abscess has formed in the soft tissues. The localizing signs of the disease vary inversely in clarity with the depth of the bone beneath the surface. In cases of infection of the tibia, localized pain, tenderness, swelling, redness and fluctuation appear relatively early, while, in a case of similar infection in the upper end of the femur or of infection in the pelvis adjacent to the hip joint, these symptoms may be late in making their appearance. Likewise, it is to be noted that in cases of infection in and around the hip the pain is not infrequently referred to the inner aspect of the knee.

If the patient is an infant or a small child, and it is difficult to determine the site of the disease in the bone, the limb can be immobilized and the patient treated for the general infection. Meanwhile the local disease progresses until an abscess forms and the diagnosis becomes obvious.

In occasional cases of hyperacute infection, the general toxemia may be so severe that localizing symptoms of the disease in the bone cannot be detected. In such instances the patient is usually suffering from primary septicemia and the osteomyelitis is not detected until either the patient's condition improves or he dies. The local disease may be discovered at necropsy, or it may develop to a point where it can be detected clinically while the patient is moribund.

Not infrequently, when the patient is first seen by the physician his general condition is good and he is not acutely ill. There may be a slight elevation of the temperature (99° to 100° F.), but little or no general malaise. The only symptoms may be pain and stiffness of the extremity. On physical examination there may be only tenderness over the involved region or there may also be swelling, red-

increase in pain there are restlessness, inability to sleep and exhaustion to a variable degree. As a result, there is also a decreased intake of fluids, which causes dehydration.

In fulminating infections there may be coma or delirium and there may be diarrhea or vomiting, or both. As the disease progresses and the fever continues for a period of days, the patient loses weight rapidly and anemia develops which causes him to become pale. The temperature varies with the severity of the disease and in cases of fulminating infection it rises rapidly to 103° or 105° F. or higher. The patient becomes increasingly ill, toxemia increases and the patient rapidly becomes exhausted. The fever tends to be sustained and there is a relatively slight fall during the day. In other instances, and this is especially prone to occur when septicemia is present, there is an intermittent type of fever, usually with an evening rise and a morning fall. The difference between the morning and the evening temperature may be 4° or 5°.

The pulse is rapid and is at first full and strong, but as the disease continues and exhaustion and toxemia progress it becomes weak and threadlike and may be uncountable. Usually, the pulse rate roughly follows the temperature curve.

On physical examination in a case of severe infection, the patient may be obviously sick and appear to be dehydrated. He may be irritable and appear to be in considerable pain. Not only may he refuse to move the involved extremity but he may object to its being examined or even touched. The joints adjacent to the infection are *usually maintained in a position of moderate flexion by muscle* spasm, and extension is not permitted. However, unless the joint itself is involved it is usually possible to increase the flexion without inflicting severe pain if the limb is handled very gently.

The first sign of the local disease is a region of tenderness. In the beginning this is sharply localized and in a case in which a long bone is involved, is usually present over the diaphysis, near the epiphysis. This tenderness makes its appearance before there is visible or palpable swelling, redness or local warmth. If the patient is a young child, it is frequently difficult to determine whether or not point tenderness is present, as the patient is likely to be very irritable and to cry out whenever the extremity is touched. However, by the application of patience and gentleness it usually can be determined whether or not a given portion of the limb is tender. If the patient is an older child, this point tenderness is best elicited by slow, steady pressure. If the bone is involved and if the tenderness is periosteal, there is no pain in the beginning but as pressure is increased the

dition of the patient is good, there may be only a moderate increase in the leukocyte count, the total count ranging between 10,000 and 12,000 per cubic millimeter of blood.

In the beginning, the disease does not affect the erythrocyte count. However, with persistence of a severe pyogenic infection there is rapid development of the disease, with high temperature and toxemia, and this is accompanied by a rapid fall in the erythrocyte count and also in the concentration of hemoglobin. This anemia is probably due to actual destruction of erythrocytes by the toxins liberated by the bacteria. As the patient begins to improve and the fever disappears, the anemia improves and the erythrocyte count and concentration of hemoglobin tend to return to normal. However, this return is slow and it may be advisable to hasten it by transfusion of blood.

If the patient is very ill when he is admitted to the hospital, a blood culture should be made as soon after his admission as is practicable and other cultures should be made at intervals as long as he remains ill. The blood culture may be positive for the infecting organism in the beginning of the disease or a positive culture may be obtained in the course of the disease. A repeatedly positive blood culture is a sign of grave prognosis. The same is true of a plate culture in which more than 8 colonies per cubic centimeter of blood are present. It has been stated that in a case in which a negative blood culture is obtained, the culture may become positive after the bone has been subjected to the insult of an operation for drainage. However, data are lacking as to how frequently this occurs and also as to whether or not, when it does occur, there is a tendency for the blood culture to remain positive or whether the positive culture may be due to a shower of organisms thrown into the blood stream by the trauma of the operation. Such a shower of organisms probably would be taken care of rapidly by the normal defense mechanism of the body.

From the standpoint of prognosis and of specific therapy for bacterial infections, a blood culture should be taken as early in the disease as possible and should be repeated at intervals during the course of the disease if facilities are available.

ROENTGENOGRAPHIC FINDINGS

One of the mistakes most frequently made by practitioners of medicine is to rule out acute osteomyelitis on the basis of negative roentgenographic findings. It is to be emphasized that neither the bacteria nor the changes induced by inflammation in the organic

ness, local warmth and even fluctuation, depending on the site and duration of the disease.

In such cases the disease usually pursues a relatively mild course even without operation. The pain may persist and increase in severity during the early stage of the disease, and an older patient may describe it as throbbing or boring in character. As the disease progresses the periosteum is stripped up and eventually ruptures. Then pus passes out into the soft tissues, the pressure in the bone is decreased and the pain becomes markedly less or may almost disappear. Likewise, when this happens there is likely to be subsidence of the general toxemia, fall in the temperature, and improvement in the patient's general condition, unless he is suffering from an infection of the blood stream or unless other foci of disease have developed and are continuing their invasive activity.

Since the physician may first examine the patient at any stage in the acute disease, and since the disease may vary greatly in severity, it is to be expected that the clinical picture will vary greatly.

LABORATORY FINDINGS

The most important laboratory finding is an increase in the number of leukocytes in the circulating blood. As a rule, in a case of osteomyelitis of moderate severity, the leukocytes in the blood number from 15,000 to 25,000 per cubic millimeter. In certain severe infections there may be little or no increase in the number of leukocytes. Both of these extremes suggest a grave prognosis and, in a case in which severe toxemia is present, failure of the development of well-marked leukocytosis is suggestive that the patient's resistance is relatively low. A differential count will reveal that the leukocytes are predominantly polymorphonuclear neutrophils (85 to 95 per cent) and an Arneth count may reveal a marked shift to the left. Joyner and Smith found that a relative increase in the percentage of immature polymorphonuclear leukocytes is evidence of toxicity and that, as this is corrected and the patient's condition improves, the percentage of mature forms increases and the normal ratio is restored.

After the periosteum has ruptured and drainage has been established, either by means of an abscess which develops in the soft tissues or by drainage to the outside, and after the temperature has fallen, the leukocyte count gradually returns to normal. Drainage to the outside may result either from spontaneous rupture of the abscess or by operation. In cases of relatively mild osteomyelitis in which the temperature is not high, and in which the general con-

the diagnosis. As time passes and the disease progresses, the changes in the bone which are visible in the roentgenogram become progressively more prominent. There are seen the increasing general and local rarefaction of the bone, the increasing areas of actual destruction and dissolution of bone, the production of new bone, the increase in the density of chronically infected bone and the separation of sequestra. It is thus evident that while roentgenographic examination is of little value in the diagnosis of acute osteomyelitis, it is of considerable value in following the subsequent course of the disease.

DIFFERENTIAL DIAGNOSIS

The most important point in the differential diagnosis of osteomyelitis is that the attending physician have the disease in mind. As a rule, the diagnosis in the early course of the disease is missed, not because the physician in charge does not have sufficient knowledge to make the diagnosis or because sufficient signs and symptoms are not present to make the diagnosis, but because the possibility of acute infection in the bone is not considered. Naturally, most children who have the disease are first seen by general practitioners or by pediatricians who are constantly seeing children who have somewhat similar symptoms as a result of infection of the ear or the respiratory tract.

Later on, when the symptoms of pain and disability in any extremity become obvious, the custom is not infrequently to suspect rheumatic fever or some form of articular rheumatism. In a series of 200 cases of chronic osteomyelitis observed at the Shriners' Hospital for Crippled Children in St. Louis, in more than 20 per cent of the histories it was specifically stated that the patients had been treated by their local physicians, for from one to twelve weeks, for some other disease before the presence of osteomyelitis was suspected. Diseases which were suspected were as follows: rheumatism in fifteen cases, typhoid fever in four cases, acute rheumatic fever in three cases, phlebitis in three cases, articular sprain in three cases, malaria in two cases, influenza in two cases, pneumonia in two cases, appendicitis in two cases (operation performed in both cases), fracture (no roentgenographic examination) in two cases, blood poisoning in one case, arthritis in one case, and tuberculosis in one case. It is, of course, not known in how many of the other cases the patients were treated on the basis of a wrong diagnosis, as in only 4.5 per cent of the entire group of cases was the bone drained during the first week of the illness.

portion of the bone are shown by the roentgenogram and that inorganic elements are not changed sufficiently during the early stages of the disease to permit identification of acute osteomyelitis in the roentgenogram. Consequently, the roentgenogram may give evidence that the bone is normal when it is really the seat of an acute inflammation and may be filled with pus.

As the disease progresses, the inorganic matter of bone is destroyed and new bone is laid down. The earliest roentgenographic changes are usually found in the diaphysis and consist of an increased radiability or rarefaction of the involved region. As the disease progresses, this region becomes spotty in appearance and the bone loses its normal texture and contains numerous small, rarefied regions which are due to destruction of the trabeculae of the cancellous bone and to thinning or perforation of the cortex.

In addition to the moth-eaten or worm-eaten appearance of the metaphysis, there is also noted the production of new bone beneath the periosteum. As a rule, this is visible a few days later and indicates that the cortex has been perforated, that the periosteum has been lifted from the underlying bone, and that sufficient time has elapsed for the formation of new bone beneath the periosteum. The new bone is visible as thin, calcified lines parallel to the shaft of the bone.

Other things being equal, the period at which changes in bone may become visible in the roentgenogram varies directly with the size and density of the bone involved, and with the thickness of the soft tissue which the roentgen rays must penetrate. In other words, in a relatively small bone covered by relatively little soft tissue, such as the lower end of the radius, roentgenographic changes appear earlier than they do in a dense bone covered by thick tissue, such as the upper end of the femur. Likewise, it is noted that roentgenographic changes in compact bone of the metaphysis occur relatively late in the disease, except for the deposition of new bone beneath the periosteum. Again, probably because of the smallness of the bones and also because of the relatively slight amount of inorganic matter which they contain, the roentgenographic changes can be detected sooner if the patients are young children than if they are older children or adults. Consequently, among young children roentgenographic evidence of the disease may be seen as early as five days after the onset of symptoms, while among older children a period of from eight to ten days, or longer, usually is necessary before the changes are visible. In addition to the roentgenographic changes noted in bone, underexposed roentgenograms may disclose abscesses of soft tissues or distention of the joint capsule, which may be of use in making

In the majority of instances in which the correct diagnosis is not made early in the disease, the presence of an acute pyogenic infection is not suspected. The diagnosis most frequently made under these conditions is rheumatism. It is believed that here the term is used in a very vague manner, that it does not refer to any particular disease, but is used to include all forms of pain and disability in the extremities of unknown cause. It is to be emphasized that an acutely ill child with high fever is not rheumatic.

Acute Rheumatic Fever

This condition might be mistaken for osteomyelitis at first, but the limitation of the disease to one or more joints, and the spread to other joints while the inflammation in the joints first involved subsides, should enable one to make the diagnosis relatively early.

Sprains and Fractures

These may be suspected when the development of osteomyelitis is preceded by a rather severe injury, but the general condition of the patient should indicate to the physician that some infection is present.

Infantile Paralysis

Early in the course of infantile paralysis limited to one extremity, and associated with pain, tenderness and disability of the extremity, as well as with fever and general toxemia, the presence of acute osteomyelitis may be suspected. However, it should be rare that the presence of infantile paralysis is suspected in a case of acute osteomyelitis, even in the very early stages of the disease. Nevertheless, this does sometimes occur, especially during a period when infantile paralysis is prevalent in a community.

Tuberculosis of Bone

The diagnosis of tuberculosis of bones and joints is not infrequently made, but usually because of lack of knowledge of the characteristic slow, insidious development of the tuberculous infection in both bones and joints. Occasionally, one sees very acute tuberculous arthritis, especially of the knee or hip, associated with relatively high temperature, marked pain and tenderness and local warmth and one may suspect the presence of acute pyogenic infection. However, there is nearly always a history that signs and symptoms have been present for some weeks before the examination and that the acute condition developed gradually. In case of doubt, a leukocyte count usually will clear up the confusion as this is not, as a rule,

Even when the presence of acute hematogenous osteomyelitis is suspected, certain conditions may make the diagnosis difficult. Having made a diagnosis of acute pyogenic infection, the most difficult part of the differential diagnosis probably is to determine whether or not the infection is in the bone or in a neighboring joint, and in certain instances, such as that of the hip, this may be impossible without aspiration of the joint or exploratory operation. In most regions the site of point tenderness (p. 200) over the bone, away from the joint, is sufficient to distinguish the two conditions. In arthritis the tenderness coincides with the outline of the synovial cavity. As a rule, in cases of pyogenic arthritis the toxemia is not so severe as it is in cases of similar infection of bone; that is, during the early stages of the disease when the infection is spreading. Another differential point is that, in cases of infection of the joint, movement is usually limited in all directions, whereas in cases of infection of the bone, movement in extension is limited but flexion is relatively free. Sometimes percussion on the bone or axial pressure directed through the bone onto the articular surface may, by the elicitation of pain, aid in determining whether or not the involvement is in the bone or in the joint. In a joint such as the knee or ankle, excess of fluid can be detected by the contour of the swelling and sometimes by palpation; in the knee joint, floating of the patella can be demonstrated. However, it is to be noted that, in osteomyelitis adjacent to a joint, accumulation of fluid in the joint is not infrequent; this fluid may not be purulent but is a result of the local inflammatory reaction and its presence may not indicate an infection of the joint itself.

Cellulitis

Local infection in the soft tissues over the bone may be extremely difficult to distinguish from infection in the bone. This is especially true in cases in which cellulitis occurs over a superficial bone, such as the upper end of the ulna or of the tibia. However, as a rule the cellulitis is more widespread, the toxemia is less severe and the area of tenderness is not sharply localized as it would be expected to be in a case of osteomyelitis.

Pyogenic Bursitis

In pyogenic infection of the olecranon or prepatellar or other bursae, it is not only difficult but sometimes impossible to determine whether or not the underlying bone is involved. Consequently, these bursae should be drained and the underlying bone should be watched as sometimes the infection extends into the underlying bone and the disease of bone progresses after the bursa has been drained.

among older children and adults but should not be confused with acute hematogenous osteomyelitis.

A diagnosis of general disease, such as typhoid fever or meningitis, sometimes is made in cases of osteomyelitis, but as a rule this occurs in cases in which the local lesion of osteomyelitis either is not noted or is ignored.

COMPLICATIONS

At the outset of this chapter it was stated that although its title indicated that only acute conditions would be considered, the chronic form of the disease would enter the discussion from time to time. This statement, it was said, applied especially to the consideration of complications and prognosis.

Complications may be divided into four groups: (1) those due to the effect of the toxemia on the general condition of the patient; (2) those due to the entrance of the organisms into the blood stream; (3) those due to the extension of the local infection into surrounding tissue; and (4) those which result from the damage to the involved bone.

Complications Due to Toxemia

In any pyogenic infection toxemia causes a progressive anemia which persists as long as the infection is active and causes fever and toxemia. In acute osteomyelitis of a severe grade, anemia may develop rapidly and may be a serious complication. Amyloid disease is a condition which results from prolonged pyogenic infection. Usually this does not occur until after the infection has been present for several months. Occasionally, however, it develops in a few weeks. As a result of the condition, amyloid is deposited in the kidneys, in the liver and in other organs.

Decubitus Ulcers.—These tend to develop in cases in which the patients are very ill, have lost considerable weight, are weak and anemic, and suffer pain when they change their position in bed. In certain cases of osteomyelitis these decubitus ulcers may be sufficiently severe to be important factors in determining the outcome of the disease. They are best treated by immobilizing the patient in a plaster of paris cast, usually by placing him in a large plaster of paris spica cast in order that pressure may be removed from the involved region. If necessary, the ulcers can be dressed through windows in the cast. They can be covered with vaseline gauze or other type of gauze and left to heal under the cast just as they are in the Orr treatment of osteomyelitis. Before resorting to this type of treatment, however,

elevated in cases of tuberculosis and is nearly always elevated in cases of osteomyelitis.

Appendicitis

Acute osteomyelitis of the hip, with resultant flexion deformity and pain which extends to the abdomen, may lead one to suspect the presence of acute appendicitis unless the hip is examined. In such cases, operations for appendicitis have been performed.

Syphilis

Rarely, syphilis of bone may resemble subacute osteomyelitis of adults and at times the diagnosis is not possible without biopsy. However, syphilis of bone does not resemble acute osteomyelitis, for the latter is attended by high fever, prostration, leukocytosis and local signs of acute inflammation. Occasionally, in cases of congenital syphilis associated with separation of the epiphysis (pseudoparalysis of Parrot), the diagnosis of acute osteomyelitis may be made and the lesion may be drained before the true nature of the disease is suspected. In such instances there is usually little or no fever, little or no toxemia and little or no elevation of the leukocyte count. On the the other hand, there may be acute pain and tenderness, swelling and local warmth, coupled with pseudoparalysis of the extremity.

Scurvy

In cases of scurvy the bone may be very tender, there may be pseudoparalysis, there may be marked secondary anemia and the child may be listless and unresponsive, except that he is irritable. However, the high temperature and the leukocytosis which are characteristic of osteomyelitis are not present. Also, the dietary history, the bleeding gums, and the subperiosteal hemorrhages of which there is evidence in the roentgenogram, point to the presence of scurvy.

Scarlet Fever

In cases of scarlet fever there is, as a rule, no localization of disease in an extremity unless arthritis occurs as a late complication of the disease. However, in cases in which osteomyelitis is associated with fever a diagnosis of scarlet fever may be made and this is especially true if the patient has a rash and a strawberry tongue, which are said occasionally to be present in cases of acute pyogenic infection.

Other Diseases

Osteogenic sarcoma or other rapid new growth of bone which is painful and rapidly progressive may resemble subacute osteomyelitis

among older children and adults but should not be confused with acute hematogenous osteomyelitis.

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any necrotic tissue in the ulcer should be excised; otherwise, the drainage will be excessive and the odor unusually foul.

Complications Due to Bacteria in the Blood Stream

Septicemia.—In a certain percentage of cases of severe acute osteomyelitis, organisms enter the blood stream in sufficient numbers so that a positive blood culture is maintained over a variable length of time. In cases of hematogenous osteomyelitis the organisms enter the blood stream before the osteomyelitis develops. However, this is not considered as septicemia. As a rule, the diagnosis of septicemia is made from the first positive blood culture, but is not considered definite until two positive blood cultures have been obtained, unless a single plate culture shows more than 1 or 2 colonies in a cubic centimeter of the blood. Septicemia is a grave complication and renders the prognosis grave. The treatment is considered elsewhere. As a result of infection of the bone, even without the development of frank septicemia, bacteria may enter the blood stream and cause metastatic lesions in other bones or in the viscera.

It is possible that some of the lesions which are termed "secondary abscesses" may be the result of the primary infection, that is, of the same entry of bacteria into the blood which causes osteomyelitis. However, I believe that this rarely, if ever, occurs and that metastatic lesions which are seen frequently in cases of acute osteomyelitis are secondary to the infection in the bone.

Visceral Lesions.—In cases in which the toxemia is severe, and especially in those in which definite septicemia is demonstrable by blood culture, metastatic abscesses in the heart, lungs, kidneys and spleen, and also metastatic infection of the pleural cavity, may occur. In addition to these visceral lesions, a metastatic abscess of the brain, metastatic meningitis and, rarely, abscesses in other sites may occur occasionally. These metastatic visceral abscesses, if diagnosed, render the prognosis more grave. As a rule, they are not amenable to local treatment but must be treated as part of the general infection and, in many instances, they are discovered at necropsy.

Infection of Other Bones and Joints.—Infection of other bones is relatively common, the frequency varying greatly in the statistics of various authors and ranging from 6 per cent in Wilensky's series to 50 per cent or more in series of cases reported by other observers. In fifty, or 25 per cent, of the 200 cases of chronic osteomyelitis studied by McCarroll and me, infection of two or more bones was present when the patients were admitted to the hospital. The metastatic abscesses of bone resemble the primary lesion in that the large bones

of the extremities are most frequently involved and the abscesses tend to occur in the metaphysis, although they may occur in the shaft.

The symptoms of metastatic abscess of bone are similar to those of primary osteomyelitis, except that, as a rule, the symptoms are less pronounced. That is, the temperature is not so high, the toxemia is not so marked and the local symptoms are not so severe. This is believed to be due to the fact that by the time the metastatic abscess has developed in the bone the patient's general resistance to the infection has increased and, as a result, the infection is walled off with relative ease. Consequently, the metastatic lesions do not, as a rule, spread diffusely through the bone but tend to be localized. For the most part, they occur in the acute stage of the disease. Occasionally, however, they may develop in cases of chronic osteomyelitis. On the other hand, they may occur during the acute stage, remain as silent foci for an indefinite period, become active later and then be brought to the attention of the patient and the physician.

As a rule, only one or two bones are affected, although in certain cases as many as a dozen or more bones may be concerned and new foci may appear for months or years.

Pyogenic arthritis may occur either by direct extension, as will be mentioned later, or as a metastatic involvement of the joint. It is my impression that when a secondary infection of a joint occurs as a result of infection of the blood stream it is more likely to be a streptococcic infection than it is to be a staphylococcic infection.

Bisgard, in a review of 217 cases of acute and chronic osteomyelitis observed at the University of Chicago Clinic, found evidence of pyogenic arthritis by the hematogenous route of infection in nine, or 4.1 per cent, of the cases. When this complication occurs, the infected joint should be aspirated or drained and treated either by immobilization or by active movement and traction, according to the dictates of the surgeon.

Complications Resulting from Direct Extension

The most frequent complication which results from direct extension of the infection into the adjacent tissues is pyogenic *arthritis.* The joint may be affected by extension of the infection through the epiphyseal line. This occurs in a considerable number of cases in which there is a severe and long-continued infection in the metaphysis and in which the infection is permitted to remain in the bone without drainage. It is especially likely to occur among older children whose epiphyseal cartilage is relatively thin and offers a weak barrier to the spread of the infection from the metaphysis, or among

adults, who have no epiphyseal cartilage. Occasionally, the infection may begin in the epiphysis and, in such an instance, it is to be expected that the joint will be involved relatively early. Finally, the joint may be involved by direct extension of the disease outside of the bone, either subperiosteally across the epiphyseal line or extraperiosteally through the soft tissues. In instances in which part of the metaphysis is intrasynovial, the disease may extend directly through the periosteum and synovial surface to reach the joint cavity.

Infection of the joint by extension occurred in forty-two, or 19.3 per cent, of the cases reported by Bisgard. In 100 of the 200 cases of chronic osteomyelitis reported by McCarroll and me, one or more joints were involved sufficiently to interfere with function. It is to be noted, however, that the patients concerned in the report by McCarroll and me had chronic osteomyelitis which had not healed and that they had been sent to the hospital for the treatment of chronic infection. Consequently, it would be expected that infections in joints, and also metastatic abscesses of bone, would be of more frequent occurrence in this group of cases than in a series of cases of acute osteomyelitis. The hip, knee and ankle are the joints most frequently involved, and involvement occurs in the order mentioned. The hip is most frequently involved because the metaphysis of the femur lies within the articular cavity, as does the epiphyseal line. The same is true to a lesser degree of the knee, and in the ankle the articular cavity extends up beyond the epiphyseal line between the tibia and fibula.

In osteomyelitis of the tarsal or carpal bones, infection of the adjacent joint is the rule. Not frequently, the disease is widespread in the tarsal or carpal regions. Likewise, infection of the patella or of the olecranon usually involves the adjacent joint by direct extension just as would infection of the epiphysis. It is further to be noted that since infection tends to travel down hill, infection of the elbow joint is particularly to be expected in association with osteomyelitis of the humerus, either of the upper or of the lower end. The severity of the infection of the joint varies greatly. It is to be expected that any infection in a bone near a joint may cause sympathetic synovitis in the joint, from the fluid of which, however, bacteria may not grow on culture.

On the other hand, with extension of the disease into the joint purulent arthritis may develop. This may be severe, may cause complete destruction of the joint and *ankylosis* may result. The purulent arthritis, however, may be *relatively mild, may clear up without* treatment and only minor loss of function may result. All gradations

between the two extremes occur. As a rule, in the treatment of acute osteomyelitis, if the bone is adequately drained, infection in the joint may be ignored. An exception to this is the hip joint. I believe that when this joint is known to be infected by pyogenic organisms it should be drained as soon as the condition of the patient warrants surgical interference. Occasionally, it may be advisable to incise and drain the knee in a case of acute osteomyelitis of an adjacent portion of the femur or of the tibia. In most instances, however, the treatment and immobilization applied to the infection in the bone are sufficient to take care of the joint and it is rare that the pyogenic arthritis dominates the picture.

In the hip joint, a pathologic *dislocation* occurs not infrequently, especially among young children. In many instances this is due to, or accompanied by, epiphyseal separation and necrosis of the head of the femur. In the knee joint, *subluxation* may occur as a result of marked flexion contracture in a case in which this deformity has not been prevented. Consequently, when a joint is involved by purulent arthritis, an effort should be made to maintain the extremity in good functional position. If the condition permits, the extremity should be immobilized in traction and, if indicated, the joint should be drained surgically.

Tenosynovitis also may result from direct extension of the disease. This is particularly likely to occur in regions in which the tendon sheaths closely approximate the bone. Therefore, the dorsal tendons of the wrist are likely to be involved in cases of disease of the lower end of the radius. Tenosynovitis may occur as a result of operations for drainage in which tendon sheaths have been opened inadvertently. Consequently, in operations for acute infections of bone, care should be taken to avoid tendon sheaths if possible.

Thrombophlebitis may occur if the infection has spread from the bone into the adjacent soft tissues. Occasionally, thrombosis of an important vein may result, and the thrombosis or thrombophlebitis may be septic and may produce fatal septicemia. Likewise, very rarely, the infection extending from the bone may surround and erode an artery of sufficient size to cause a secondary hemorrhage.

Osteomyelitis of bones of the skull not infrequently is complicated by the development of *abscesses in the brain* or by *meningitis*. Likewise, osteomyelitis of a rib may be complicated by *empyema* and osteomyelitis of the orbital bones by *panophthalmitis*. Osteomyelitis of the spinal column may result in the development of *abscesses of the posterior mediastinum*, or in *retroperitoneal abscesses*, or the spinal cord may be involved by pressure or by extension. In

cases in which chronic osteomyelitis has persisted for several years, *carcinoma* or, very rarely, *sarcoma* may develop in the walls of a sinus as a result of the long-continued chronic irritation. When a malignant tumor of this type develops in an old osteomyelitic sinus *it is believed that prompt amputation is the treatment of choice.*

Complications Due to Damage to the Involved Bone

The disease in the bone itself may cause epiphyseal separation, pathologic fracture, deformity or disturbance of growth.

Epiphyseal Separation.—Epiphyseal separations are relatively rare. They occur during the late stage of the acute disease as a result of the destruction of the metaphysis adjacent to the epiphysis, which is usually combined with some slight strain. As a rule, displacement of the epiphysis can be prevented by adequate splinting, except in the case of the femur, where the head of the femur may be cut off from its blood supply and the entire head may become necrotic and remain indefinitely as a sequestrum in the infected hip joint while the neck of the femur is more or less completely destroyed, and the shaft and base of the neck are displaced upward and backward.

Pathologic Fracture.—A pathologic fracture may result just as does epiphyseal separation, late in the course of the acute disease, because of the marked destruction of the entire section of the shaft or of the metaphysis of the bone. Also, pathologic fractures may develop postoperatively in cases of chronic osteomyelitis as a result of a radical attempt at cure by the removal of a large portion of the shaft of the bone, the operation having been followed by insufficient protection of the relatively weak and brittle bone. As a rule, these pathologic fractures heal without difficulty if it is possible to maintain fair position of the fragments. Occasionally, however, if the operation has been very extensive and followed by flaring up of infection, necrosis of the ends of these fragments may result and sufficient involucrum may not develop to result in healing. In such instances, the nonunion requires some later operative procedure.

Disturbances of Growth.—Disturbances of growth due to osteomyelitis occur during the chronic stage of the disease. The most frequent of these is thickening of the bone, which occurs in almost every case. This thickening varies considerably in degree and is the result of the deposition of new bone beneath the periosteum of the shaft in the infected region. In some instances, the bone is increased to *two or three times* its normal size.

The most important disturbance of growth, however, is shorten-

ing. This is due to damage to, or destruction of, the epiphyseal cartilage by the acute disease. The frequency with which disturbance of growth of this type has been noted to occur varies greatly in different series of cases. Wilson and McKeever[28, 29] found it present in eighteen of eighty-five cases; that is, an incidence of 21 per cent. As a rule, the shortening is not great unless the epiphysis of a relatively young child is destroyed, in which case the shortening may amount to 3 to 4 inches (about 7.5 to 10 cm.) or more and may cause marked crippling. Relatively slight shortening may be important if one or two parallel bones are affected to such a degree that deformity may occur. Slight shortening of the radius or ulna, or of the tibia or fibula, would cause deformity of the wrist or ankle joint.

The next most important disturbance in growth is change in the alignment of the limb as a result of destruction of the epiphysis on one side. This may result in a knock-knee or bowleg deformity or, if the posterior portion of the epiphysis is destroyed while the anterior portion continues to grow, marked anterior bowing of the lower portion of the femur or of the upper portion of the tibia may result.

Lengthening occurs in about the same proportion of cases as does shortening. Usually, the lengthening is not of sufficient importance to be noted. However, it occasionally may amount to 1 inch (2.5 cm.) or more in an extremity. It is most frequent in cases of chronic osteomyelitis of the femur and in rare instances it may also affect uninvolved bones of the extremity. In a case of osteomyelitis of the femur there may be some actual lengthening of the tibia and fibula. It is believed that the increased length is due to stimulation of growth in the epiphyseal zone, perhaps by the excessive blood supply.

In cases of severe osteomyelitis there may be retardation of growth of the extremity beyond the lesion of the bone, so that the patient's foot or hand is noticeably smaller than that on the normal side. In the case of a foot, this may make it necessary to get two sizes of shoes in order that the patient may be properly fitted. This retardation of growth is probably due to lack of use.

PROGNOSIS

In a preceding portion of this chapter, as well as at the beginning of the chapter itself, the statement was made that the chronic form of the disease would enter the discussion from time to time, and particularly when complications and prognosis came up for consideration.

At the present time, it is not possible to make any definite statement as to the usual mortality rate in cases of acute hematogenous

osteomyelitis as there is a tremendous difference in the mortality rate in the various series of cases reported in the literature. It ranges from less than 2 per cent to more than 30 per cent. Obviously the various surgeons are dealing with different types of patients; otherwise, the treatment adopted by those surgeons who report the lowest mortality would soon become universal. I believe that a fair mortality rate in a large series of cases of acute osteomyelitis of the long bones is from 10 to 15 per cent. It is possible that by the use of sulfathiazole or sulfadiazine this rate may be reduced considerably.

Since there is such a marked difference in the severity of the disease in different cases, it is important to note that the prognosis varies with the severity of the disease. In other words, the patient who enters the hospital with a temperature as high as 104° F. or higher has a definitely poorer prognosis than does a patient who enters the hospital in the same stage of the disease with a temperature of 101° F. Likewise, a patient who has severe toxemia has a poorer prognosis than does a patient who is in good general condition. Furthermore, the mortality rate varies somewhat with the size of the bone affected, that is, infection of a large bone is likely to be more dangerous than is infection of a small bone.

A positive blood culture, especially at the second examination, greatly increases the gravity of the prognosis, as in such cases septicemia is definite and, by and large, the mortality rate of staphylococcic or streptococcic septicemia is in the neighborhood of 70 per cent. However, by the use of sulfathiazole and possibly by the use of antitoxin, in addition to other measures to be mentioned, the mortality rate may be greatly lowered. At the present time, however, I do not have sufficient data to give an opinion as to what the eventual mortality rate of acute osteomyelitis will be when the disease is treated by modern methods, including chemotherapy.

There is also the prognosis as to complete recovery or recovery with crippling. At the present time, I know of no adequate statistics which give the percentage of patients with acute hematogenous osteomyelitis who recover completely and in what percentage of cases chronic osteomyelitis develops. It is fair to assume that a chronic form of the disease will develop, and sequestra will occur, in the great majority of cases of staphylococcic osteomyelitis in which the patients are more than two years of age. It is probable that in the majority of cases in which the disease is due to streptococci, and in which secondary infection with staphylococci does not occur, recovery without sequestration and complete healing will occur. On the other hand, a certain percentage of these streptococcic infections of bone

involve the joints and result in crippling or involvement of the epiphyseal line and shortening of the limb.

The percentage of cases of staphylococcic infection in which involvement of the adjacent joint occurs is not known definitely, as here, too, there is considerable variation in statistics. In 100 of 200 cases of chronic osteomyelitis which McCarroll and I observed at a Shriners' Hospital for Crippled Children, there was involvement of one or more joints of the extremity. This is considerably higher than the percentage given by other observers. However, all of the 200 patients had chronic osteomyelitis. It is probable that in a series of cases of acute osteomyelitis, the incidence of articular involvement in the cases in which the patients survive will be in the neighborhood of 25 per cent. This will, of course, include many cases in which the infection is mild. The articular involvement is, in some instances, due to perforation at the epiphyseal line and involvement of the epiphysis, or to direct extension along the surface of the bone across the epiphyseal line. In certain joints, particularly the hip joint, where the epiphyseal line is intracapsular, articular involvement is almost the rule if the infection is situated in the neck of the femur. Much the same is true in regard to shortening which, as a rule, is due to involvement of the epiphyseal line. If the epiphyseal line of a young child is completely destroyed, the shortening will be marked. On the other hand, many epiphyses are damaged but not completely destroyed, and there may be some irregularity of growth, or if infection in the bone is prolonged, there may be acceleration of growth so that as much as 1 inch (2.5 cm.) or more of actual lengthening of the bone may result. Much of what is said in this paragraph also appeared, it will be recalled, under the subheading Disturbances of Growth (p. 214).

There is also to be considered the possibility of cure of the chronic disease once it has developed. In the series of 200 consecutive cases of chronic osteomyelitis reported by McCarroll and me, it was possible to follow ninety-eight of the patients for three years or longer. Of these, sixty were apparently cured and had shown no evidence of active disease during the three years or more, while thirty-eight had evidence of active disease during that time. Of these thirty-eight patients, twenty-four apparently had been well during part of the period, but the disease had recurred and abscesses had formed. In the remaining fourteen cases the disease remained clinically active during the entire period of observation.

It is thus evident that in a considerable percentage of cases of chronic osteomyelitis permanent cure of the disease short of ampu-

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The problem is a surgical one and not entirely one of immunology. It should not be anticipated that general resistance of the patient will increase sufficiently to combat the local and general infection without adequate drainage of the abscess in the bone. There are, of course, instances of overwhelming infection of the blood stream in which the patient is suffering from extreme toxemia and is in no condition for operation. In such cases the general condition of the patient should be given first consideration and, when and if the patient's general condition has improved sufficiently, the focus in the bone should be dealt with surgically. On the other hand, there are undoubtedly many patients with acute hematogenous osteomyelitis who, if seen early and operated on early, can be completely cured by the operation; the operative wounds will heal with no resulting chronic osteomyelitis. Had these patients been let alone and treated conservatively, a variable amount of invasion and necrosis of bone would have occurred, with resulting chronic disease; or perhaps the infection would have continued to spread and would have caused the death of the patients.

Since the disease varies greatly in its course and in its severity, it is evident that treatment cannot be standardized and that in each case the disease must be considered as an individual problem which must be met according to the best principles of surgery. For this reason, in a previous paper, I divided cases of acute hematogenous osteomyelitis into the four following, overlapping groups: (1) cases of mild infection in which the patients are not acutely ill; (2) cases of severe, spreading infection in which the general condition of the patients is good; (3) cases of spreading infection in which the patients are severely ill and in poor general condition, and (4) cases in which the infection has localized and is subsiding.

From what has just been said, it is evident that both the general condition of the patient and the local infection in the bone should be considered in planning the treatment of the individual patient. It also should be noted that early diagnosis is extremely important in an infection due either to staphylococci or streptococci, as these organisms are characterized by their ability and tendency to invade the surrounding tissues, and infection caused by either of these organisms has a tendency to spread. Consequently, the earlier the condition can be diagnosed and treatment started, the better the chance of limiting the spread of the infection. With this in mind, it is to be pointed out that, while every patient with osteomyelitis does not need an immediate operation, and in some cases immediate operation is definitely contraindicated, in every case the disease constitutes

tation of the extremity above the site of the disease is sometimes not possible.

The functional result also must be determined in cases of chronic osteomyelitis. The results are considered good if the disease appears to have been arrested without residual deformity, important disturbance of growth or definite loss of function in the adjacent joint. This result was obtained in 25.5 per cent of the 200 cases. A fair result, with only slight deformity or slight impairment of articular function, and slight disturbance of growth, was obtained in 28 per cent and poor results in 35.5 per cent. Data were not available in remaining cases.

Chronic osteomyelitis may remain dormant for years and then become active again, and increased physical activity tends to cause a flare-up of old, dormant infections in bone. Therefore, it is believed that men who exhibit evidence of chronic osteomyelitis in the lower extremities and those who exhibit evidence of old, multiple infections of bone should not be admitted to military service. Men with old infections of bone in the upper extremity which have remained healed for several years and have not caused symptoms during this period may be selected for military service.

TREATMENT FOR THE DISEASE AS IT AFFECTS CHILDREN AND ADOLESCENTS

In recent years many articles on the treatment of acute hematogenous osteomyelitis have been published and there is considerable difference of opinion among various authors. Some believe that every patient with acute hematogenous osteomyelitis is suffering from general septicemia due to staphylococci or streptococci, as the case may be. They believe that the infection in the bone is not only secondary, and incidental to the general infection, but that it is a valuable factor as, by the localization of the disease, it gives an opportunity for antibodies to form and combat the general infection. Others believe that the infection in the bone is the cause of all of the difficulty and that the lesion should be incised and drained, or excised, as early as possible.

It is, of course, obvious that bacteria must have been present in the blood stream in order that they may have reached the bone by this route. However, it is my opinion that in a case of acute osteomyelitis the disease in the bone is a very important part of the picture and that, whether or not the patient has septicemia at the time of the examination, the disease in the bone should not be ignored.

part should be immobilized (p. 225). Then certain laboratory tests should be made. Routine urinalysis should be made if urine can be obtained. Examination of the blood, which includes leukocyte count, differential count, erythrocyte count, and estimation of the concentration of hemoglobin, should be made. If the patient is severely ill, blood should be taken for culture immediately. At the time that this specimen of blood is taken, blood also should be taken in order that it may be matched for transfusion; the matching should be done as promptly as possible, especially when the patient has been acutely ill for some days.

General Treatment

Treatment should be started as soon as possible after the patient has entered the hospital. The general treatment includes (1) chemotherapy; (2) relief of pain; (3) correction of dehydration; (4) correction of anemia, if present; (5) correction of toxemia by administration of antitoxin when indicated, and (6) specific general measures to combat the infection. Attention then should be given to the local treatment of the infection.

Chemotherapy.—A full dose of *sulfathiazole* or *sulfadiazine* should be given by mouth as soon as possible after the tentative diagnosis of acute osteomyelitis has been made. If for any reason the drugs cannot be given by mouth they can be given intravenously as the sodium salt; 1 gm. of the drug is dissolved in 20 cc. of sterile distilled water. When given in the vein the drug should be administered slowly, and care should be taken that no extravasation of the solution occurs as it is quite alkaline and may cause necrosis of the tissues. These drugs are effective against both staphylococci and streptococci. Sulfanilamide should not be used, because in therapeutic doses it has little or no effect on staphylococci in the blood stream or in the tissues, and it may actually lower the patient's general resistance and do more harm than good.

If the infection is known to be due to streptococci, sulfanilamide, sulfathiazole or sulfadiazine may be used. A staphylococcus is the offending organism in more than 90 per cent of the cases in which the patients are more than two years of age; hence, sulfathiazole or sulfadiazine is the drug of choice in such cases until some more effective bacteriostatic agent is discovered.

If the patient is an *adult*, I give by mouth 30 grains (2 gm.) of any of these drugs when he is admitted to the hospital. This is followed in four hours by 15 grains (1 gm.), and this dose is repeated every four to six hours until the patient's general condition improves

an acute surgical emergency. Treatment should be begun immediately; the patient should be seen by a surgeon at the earliest possible moment and he should decide when to operate. His decision should be based on the general condition of the patient, the severity of the infection, the possibility of localizing the disease—that is, the surgeon's ability to decide exactly where it is—and the facilities for operation, which include the surgeon's training and capability. Consequently, a patient suspected of having osteomyelitis should be taken to a hospital as soon as possible after suspicion of the presence of the disease arises.

Procedures on Admission to Hospital

At the hospital the following things should be done:

1. An adequate history should be obtained from the parents or from the patient as soon as possible after his admission. This should take into consideration the first symptoms of the disease, the possibility of trauma and other predisposing causes or conditions, such as general or local infection, which may have lowered the patient's resistance or acted as foci for the entrance of the bacteria into the blood stream. It is important also to know how long the symptoms have been present. The previous course of the temperature, if known, should be noted, as well as whether or not the onset was with a chill. Inquiry should be made as to the patient's intake of food and fluids and whether or not nausea, vomiting or diarrhea has been present.

2. Then a physical examination should be made. The patient should be handled as gently as possible. If he is severely ill the examination should be directed at the diseased part; the patient should not be submitted to complete physical examination, including investigation of the ears, nose, throat, nervous system and other parts of the body. In other words, the patient should be disturbed as little as possible. Once acute osteomyelitis is suspected, the diagnosis is not, as a rule, difficult. The important point is to find out, as nearly as possible, the exact site of the infection in the bone. Also, it is necessary to know whether or not the infection has broken through the cortex of the bone and has formed an abscess, either beneath the periosteum or in the soft tissues. The temperature, pulse and respiration should be recorded. Also, the severity of the toxemia should be estimated and whether or not the patient is stuporous, delirious or comatose. Likewise, estimate should be made of whether or not the patient is dehydrated.

3. Following the physical examination, as will be stated, the

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and the fever decreases or until there is evidence of toxic effects of the drug.

If the patient is ten years of age, I use half of the adult dose, and if he is five years of age I use a fourth of the adult dose. As a rule, children tolerate the drug very well.

Probably the most important toxic effect of sulfathiazole and sulfadiazine is damage to the kidneys. For this reason, patients who are taking these drugs should be given large amounts of fluid; the urine should be examined daily and the daily intake of fluids and output of urine should be recorded.

Prolonged administration of the drugs is not without danger and administration should be stopped a few days after the patient's temperature has reached normal. When administered by mouth the drugs have relatively little effect on the local disease in the bone; they should not be given indefinitely in the futile hope that they will sterilize the necrotic and infected bone.

Relief of Pain.—In many cases the patients have lost a considerable amount of sleep because of pain and have become exhausted before they enter the hospital. In such cases a full dose of morphine, or of whatever other sedative preparation the surgeon may prefer, should be administered as soon as possible after the patient has entered the hospital, even before the history has been taken and physical examination made. Administration of the sedative agent should be continued as long as necessary during the acute stage of the disease.

Correction of Dehydration.—In certain cases the patient is able to take ample quantities of fluid by mouth. In such cases, fluids should be administered by this route. In many instances, however, toxemia is present and although the patient is dehydrated it is still not possible to correct this dehydration by oral administration of fluids. In such cases, physiologic salt solution which contains 5 per cent of dextrose should be administered intravenously. The amount to be given depends on the size of the patient and the degree of dehydration. Usually, in the case of a moderately dehydrated child, an initial dose of from 300 to 750 cc. can be given with safety.

Correction of Anemia.—If the patient has been ill for several days and well-marked anemia is present, this should be corrected by blood transfusion. As a rule, 500 to 600 cc. of blood is obtained from the donor but only part of this amount is given at one time—usually from 150 to 300 cc., depending on the age and size of the patient. The remainder of the blood is given from twelve to twenty-four hours later or after the operation.

Correction of Toxemia.—For correction of the toxemia there is now available a new, highly concentrated, highly purified staphylococcic antitoxin. By the use of this antitoxin Baker and Shands obtained excellent results. In thirty cases in which antitoxin was not used the mortality rate was 70 per cent and in thirty-five cases in which antitoxin was used the mortality rate was 25.7 per cent. In other respects the treatment was essentially the same. Consequently, there can be no doubt that the serum is effective. The problem is: To what patients should the antitoxin be administered?

According to Baker and Shands, the answer to this question depends on the differential leukocyte count. If there is a relative decrease in the segmented forms and a relative increase in the nonsegmented forms (20 per cent or more) of the polymorphonuclear leukocytes they said that antitoxin should be given immediately. Since there appears to be no danger in administration of the antitoxin in its present highly purified form, it seems wise to administer it in every case in which there is evidence of severe toxemia; that is, every patient who has high temperature, increased pulse rate, respiratory distress, flushed face and dilated pupils, stupor or delirium should be given antitoxin if it is available. This is because in more than 90 per cent of cases of acute hematogenous osteomyelitis in which the patients are more than two years of age the offending organism is the staphylococcus.

Baker and Shands recommended use of the intradermal test for sensitivity with 0.1 cc. of undiluted antitoxin and 0.1 cc. of a 1:10 dilution of normal horse serum as a control. They said that the patient frequently responds negatively to the horse serum but immediately with an urticarial wheal to the antitoxin. Patients who react in this manner always should be given the first dose intramuscularly and subsequent doses intravenously. The first dose is usually 20,000 units intramuscularly in cases in which the patients are less than ten years of age and up to 40,000 units in cases in which the patients are older. The size of the dose varies with the degree of toxemia as well as with the age of the patient. Usually the initial dose is followed in four hours by the intravenous administration of 40,000 to 60,000 units; this is repeated in twenty-four hours and then is repeated daily as long as severe toxemia persists. One patient who was six years of age received 700,000 units and another who was eight years of age received 600,000 units, each within a period of three weeks, and neither patient disclosed any evidence of sensitivity.

The antitoxin is expensive and probably it will be largely supplanted by sulfathiazole and sulfadiazine. In cases in which the tox-

emia is extreme, it seems advisable to use both chemotherapy and antitoxin.

Specific Agents to Combat the Infection.—As specific agents against the bacteria, it is necessary to consider preparations such as toxoid, which increases the immunity of the patient, specific antistaphylococcic serum, antistreptococcic serum, bacteriophage, and chemotherapy.

I believe that it is useless to consider the administration of toxoids in an effort to increase the patient's immunity in a case of acute osteomyelitis. The course of the disease is so rapid that there will not be sufficient time for the toxoid to have any beneficial effect, as it takes about two weeks before immunity of any value can be established, and before this time the course of the disease will have been decided.

As regards specific antiserum, Julianelle has prepared from rabbits an antistaphylococcic serum which appears to be highly effective experimentally and has proved of considerable value in clinical practice. At present this serum is not available for general distribution. When and if its clinical value has been adequately proved, it will be made available for general use, and when it is made available it can be used as a specific antistaphylococcic serum, combined with the antitoxin, as the two will tend to work together, that is, the antitoxin will detoxicate the toxin while the specific serum will tend to aid in the removal of the bacteria from the blood. It is not known as yet what effect the serum will have on the local lesion. It is known that the antitoxin can have little or no effect on it. In four of Julianelle's cases in which the patients died of the disease. the blood was sterilized before death. This is evidence of the high potency of the serum. However, the demonstrated efficiency of sulfathiazole and of sulfadiazine against staphylococci makes it probable that the specific antiserum will be reserved for cases in which the patients do not respond to chemotherapy.

The question as to whether or not bacteriophage should be used is one which I am not able to decide. In a previous paper I ventured the opinion that bacteriophage would be of little value, since the statistics of MacNeal and Frisbee indicated that in 100 cases in which bacteriophage was used the mortality rate was 70 per cent, that is, about the same as the mortality rate in cases of staphylococcic septicemia in which bacteriophage is not used. However, in a recent paper, Longacre, Zaytzeff-Jern and Meleney reported that seventeen, or 47.2 per cent, of thirty-six patients who received bacteriophage

died. In a series of twenty-one cases which were observed more recently and in which a bacteriophage of so-called double potency was used only six, or 28.5 per cent, of the patients died. In fifty-four control cases of staphylococcic septicemia in which no bacteriophage was used, there were forty-four deaths, that is, a mortality rate of 81.4 per cent. It is thought that the cases were similar and that other than the administration of the bacteriophage of so-called double potency, the treatment of the two groups was similar. Consequently, with the double potency bacteriophage the mortality rate of staphylococcic septicemia appears to have been reduced from 81.4 per cent to 28.5 per cent. From these figures one cannot but recommend that bacteriophage be used if the specific bacteriophage as used by Longacre, Zaytzeff-Jern and Meleney is available. To be successful, the bacteriophage must be of high potency, must be given in large doses and early in the course of the disease. This phase of the problem of the treatment of staphylococcic infection will have to be decided in the future since, at present, it can only be recommended that if bacteriophage of the type used by Longacre and his co-workers is available it may be used. On the other hand, it is to be noted that bacteriophage and antitoxin should not be used together, as they tend to neutralize each other. If the so-called double potency bacteriophage is not available, patients who have staphylococcic septicemia should be treated with antitoxin. It is probable, however, that as sulfathiazole and sulfadiazine are available there will be little need for the bacteriophage.

Local Treatment of the Disease

The first principle of local treatment of any infection is immobilization of the part. This should be done as soon as possible after the history has been taken and physical examination has been completed, and before laboratory tests have been made. The extremity can be immobilized in a large pillow splint applied not too tightly; in a very large, hot, wet dressing; by traction; by sand bags, or by whatever method may appeal to the surgeon. The important thing is that immobilization is an adjunct in relieving the pain and also in localizing and combating the infection.

Whether heat or cold is indicated is always a doubtful question in my mind. I usually apply a very large, hot, wet dressing until the patient is ready for the operation. This dressing is not changed or removed until the patient is on the operating table.

In addition to immobilization, the local treatment consists of

surgical operation. It is believed that in every case of acute osteomyelitis operation is indicated. When it should be performed, and how extensive the operation should be, will be considered in some detail. While it is granted that, in certain cases, if the patient is treated conservatively the infection in the bone will quiet down and even, in rare instances, healing may be complete and there may be no further trouble, it is still believed that this is not good surgical treatment and that every patient who has acute osteomyelitis should be treated by incision and drainage if his condition can be improved to withstand the operation. Consequently, it is believed that the preliminary treatment of severely ill children should be directed largely toward preparing them for operation.

Choice of Time for Operation.—The question is: When should the operation be performed? I believe that operation should be performed *as early as is safe,* because *drainage of bone tends to accomplish the following:* 1. It lessens the amount of toxic material which is thrown into the general circulation. 2. It tends to lessen the spread of the infection in the bone. 3. It tends to lessen the danger of infection of the blood stream and the development of metastatic lesions.

If one refers to the classification mentioned previously (p. 219), it may be said that patients who are not very ill and who have a mild infection should be operated on relatively soon after their admission, because, by so doing, I believe that the infection in the bone may be limited. It is well known that in certain cases of osteomyelitis the disease starts mildly and becomes more severe as time passes.

In *Group 2, which includes patients who have a severe, spreading* infection, but who are in good general condition, I believe that it is more urgent to operate early because I think early operation increases the chance of survival and tends to lessen the amount of destruction of bone.

Group 3 includes patients who are suffering from severe toxemia and whose general condition is poor. I believe that these patients should not be operated on immediately after they enter the hospital. It is necessary that their fluid balance be restored, that they be given an opportunity to rest and recuperate by the administration of sedative agents, fluids, possibly blood, and antitoxin if it is available. There is no doubt that an operation, especially an ill-planned, long-drawn-out operation, on an extremely ill patient is ill advised. Consequently, for these patients the operation should be deferred, but this postponement is a matter of hours and not of day or weeks. A full dose of sulfathiazole or sulfadiazine should be given on admission (p. 221). Then, as soon as the patient has had some rest, the fluid balance has

been restored, the anemia has been corrected and the toxins neutralized, the bone should be opened, or at least the periosteum should be incised.

The patients in Group 4 have passed the crest of their illness and their temperature is falling; that is, the disease has been present for some time and has run its acute course before they have been brought to the hospital. In such cases there is little danger of further spread of the disease in the bone. Also, there is relatively little danger of infection of the blood stream or of metastatic lesions. Consequently, operation can be deferred until convenient. However, there is no point in deferring the operation longer than necessary because, even in cases in which patients have been almost afebrile, I have seen the disease continue to spread in the original bone and even involve and cripple an adjacent joint.

Preparation of Patient for Operation.—The patient is prepared for the operation by a suitable dose of morphine and atropine if general anesthesia is to be used, or only morphine if local anesthesia is to be employed. As a rule, I prefer *nitrous oxide and oxygen* or another form of general anesthesia for children because, with proper planning, the operation usually can be performed in a very few minutes. If the patient is a small child who is severely ill, local anesthesia may cause more excitement and do more harm than will general anesthesia of short duration.

The limb is not prepared for operation in the usual way. The patient is placed on the operating table with the immobilizing splint or dressing in place. Then the limb is exposed, dried, and the point of maximal tenderness is carefully noted by the surgeon in order that he can plan the operation in detail before the incision is made. If much hair is present this is dry shaved with a safety razor. The skin is then painted with mercresin, tincture of merthiolate, or whatever other antiseptic agent the surgeon prefers. If the general condition of the patient is not good, administration of the anesthetic agent is not started until the surgeon is through scrubbing his hands and has donned his operating gown and gloves. Then, when everything is ready, administration of the anesthetic agent is started and, when the patient is sufficiently under anesthesia, the limb is draped if this has not been done previously.

Surgical Procedure.—As a rule, a tourniquet is not used. I believe that the handling of the limb and the pressure on the tissues incident to the application of a tourniquet may do more harm than good. With good technic it is possible to plan the operation in such a way that large vessels will not be cut. Vessels which are cut are clamped

before, or almost as soon as, they are cut. Consequently, very little blood may be lost.

As soon as the patient is sufficiently anesthetized, the incision should be made. Usually, this is a longitudinal incision over, or nearly over, the point of maximal tenderness. The operation should be carried out with precision and dispatch, but not hurriedly. The bone should be approached through as nearly a bloodless field as possible, that is, through an incision which avoids important vessels and nerves. If possible, the incision should pass through planes between muscles rather than through muscle tissue, and should be no longer than is necessary for adequate drainage. There is no point in making a very long incision when the sole purpose of the operation is to drain an infected region.

The incision is carried directly down to the bone. Any bleeding vessels which are encountered are clamped promptly, as it is important that the patient lose as little blood as possible. When the bone is reached, the periosteum is split over the site of the suspected infection. The periosteum may be edematous; there may be a collection of fluid or even of pus beneath the periosteum and the bone may be bare. On the other hand, the periosteum may be intact and adherent, and the bone beneath it may be normal.

In a case in which the patient is a very sick child, it is probably wise merely to incise the periosteum, especially if an extra-osseous, subperiosteal abscess is encountered. As a rule, however, a window should be removed from the bone. This is especially true among older children and adults, as the freedom with which infection can be drained through the haversian canals decreases progressively with the age of the individual.

It is thus evident that other conditions being the same, the bone is opened more frequently among older children than it is among young children. Likewise, the bone is opened routinely unless fluid or pus is present beneath the periosteum, because infection may be walled off in the bone and may even be present there under pressure, whereas, if fluid or pus is present beneath the periosteum, this is evidence that there is at least some exit for the infection through the nutrient canals of the bone.

As the infection is usually in the metaphysis, the incision is made close to the epiphyseal line and this may be exposed. Care should be taken not to extend the incision into the neighboring joint cavity or to damage the epiphyseal line, and also not to split the periosteum across the epiphyseal line. Consequently, the periosteum over the metaphysis is split longitudinally, beginning a short distance from

the epiphyseal line. Then a short transverse incision is made in the periosteum about ½ inch (1.25 cm.) from the epiphyseal line. This permits the periosteum to be stripped back sufficiently to drill, or to make a window in, the metaphysis without endangering the cartilage of the epiphysis. At this point, a small hole about ⅛ inch (0.3 cm.) in diameter is drilled through the cortex. This is to lessen the pressure within the bone and also to prevent a sudden increase in the pressure which may be caused by cutting a window in the cortex.

After the drill hole has been made, a small window, which varies in size with the size of the bone, is cut in the cortex with a thin, very sharp osteotome. Lacking such an osteotome, a series of drill holes can be made and these can be connected by chipping out the intervening bone or, if the surgeon prefers, merely a series of drill holes may be used for drainage of the underlying bone. I prefer to make the drill holes at right angles to the shaft of the bone rather than obliquely toward the epiphyseal line, as was suggested by Starr. This is because the epiphysis may be inadvertently injured by the oblique drill holes, whereas there is little tendency to injury by drill holes which are at right angles to the shaft and which do not start closer than ½ inch (1.25 cm.) from the epiphyseal line.

It is to be emphasized that the bone is opened for drainage and not for removal of infected bone. Consequently, no curetting of cancellous bone is done. As a rule, the marrow canal is not opened. Occasionally, in cases of widespread infection a relatively narrow gutter is extended down to the marrow canal, or this can be entered by one or more drill holes. However, in the presence of an infection which has extended down into the marrow canal, there is usually rather widespread osteomyelitis, with an extensive extra-osseous abscess, which may be subperiosteal or may have ruptured through the periosteum. In such instances, the disease has been present for some time and it is probable that it will not spread further. Consequently, there is little need for an extensive guttering operation for drainage; if the patient is in unusually good condition, however, such an operation may be performed. The amount of work done on the bone varies inversely with the general condition of the patient; if the patient is very ill, as little work as possible should be done on the bone.

As soon as the bone has been opened sufficiently and hemostasis has been effected, and before the vaseline gauze has been placed in the wound, moderate amounts of *sulfathiazole, sulfadiazine* or *sulfanilamide* crystals are sprinkled in the wound. This will form a saturated solution of the drug in the fluids which collect in the wound, and this saturated solution will inhibit the growth of staphylococci,

although it is not bactericidal, and will lessen the amount of pus which forms in the wound. Then the wound should be packed loosely with vaseline gauze. This gauze should be so placed in the wound that it permits drainage and can be removed without difficulty at the time of the first postoperative dressing. A dry dressing should then be applied and the limb should be immobilized in a plaster-of-paris cast. If the osteomyelitis involves the femur, this cast should be a spica and should include the pelvis. If the osteomyelitis involves the lower leg, a cylinder cast which extends to the upper third of the thigh should be sufficient. In osteomyelitis of the upper extremity, unless the upper end of the humerus is involved, it is as a rule not necessary to apply a spica jacket. The cast should be applied over a relatively large, dry dressing and over an ample amount of padding, usually of sheet cotton.

Postoperative Care.—As soon as the cast has begun to set, administration of the anesthetic agent should be discontinued, the patient should be put to bed, and postoperative treatment should be started. Primarily, this consists of chemotherapy and the administration of fluids. *Dextrose* is administered intravenously or blood is transfused if necessary. A *transfusion* is indicated in cases in which a positive blood culture is suspected and in cases in which there is a considerable degree of anemia. The amount of blood transfused should be small, from 150 to 300 cc., depending on the size of the patient. If antitoxin is being used, its administration should be continued, as should other measures for combating the general infection. Likewise, sedative agents should be administered and a diet high in calories should be prescribed. The administration of *sulfathiazole* or *sulfadiazine* should be continued in full doses, depending on the weight of the patient, until the temperature falls or until symptoms of toxemia appear.

The wound is not disturbed for at least forty-eight hours and, if the condition of the patient is continuing to improve, the original dressing can be left in place for from ten days to two weeks.

After the operation it is expected that the patient's general condition will improve and that his temperature will fall gradually over a period of days or weeks. Occasionally, there is an abrupt drop in the temperature. However, this is not the rule because, since the infection is usually in cancellous bone, it is not possible to secure adequate drainage simply by removing the cortex. However, the course of the infection is turned so that instead of its tending to invade the tissues and to pour toxins into the general circulation, toxic material tends to drain out through the wound, unless it has been packed too

tightly with the vaseline gauze. It is mentioned again that the packing should be sufficiently loose so that it does not act as a plug and thus stop the opening which has been made in the bone.

As the temperature gradually declines, the patient's general condition tends to improve. In certain instances the patient continues acutely ill, toxemia continues, and the temperature remains high and the pulse rapid. In such instances the trouble may be: (1) infection of the blood stream, (2) insufficient drainage, or (3) a metastatic focus. The patient should be examined from time to time in an attempt to locate such a focus. If no such focus is present and the patient's temperature continues high, it may be advisable, and occasionally is advisable, to enlarge the original incision while the patient is under general anesthesia and to make a more extensive opening in the bone. It is to be noted that during this postoperative period the administration of sulfathiazole or sulfadiazine is continued.

If a secondary focus is found it should be drained just as was the primary focus, and this should be done as soon after it is detected as is practicable. At the end of from one to two weeks, depending on the condition of the patient and the dressing, whether or not there is a large amount of drainage, and whether or not the patient is uncomfortable, the plaster-of-paris cast should be cut to form a bivalved cast, or it should be changed, or a large window should be cut in it, and the wound should be dressed. If the vaseline packing has been properly inserted in the first place, it will not be necessary to administer an anesthetic agent for this dressing, as the vaseline packing can be lifted gently out of the wound. The edges of the skin should be wiped with dry cotton sponges and, after a moderate amount of sulfathiazole, sulfadiazine or sulfanilamide powder has been sprinkled over the surface of the wound, it should be repacked loosely with vaseline gauze and the dressing re-applied.

From this time on, the care of the patient varies with the choice of the surgeon. I use the method recommended by Orr,[16-18] that is, I pack the wound loosely with vaseline gauze and perform dressings infrequently. As a rule, the cast is changed at the time of each dressing and the skin is cleaned with soap and water and with alcohol. In certain instances, if the skin is scalded by the discharges from the wound and if small pustules or infection of hair follicles is present, the skin is thickly covered with zinc-oxide ointment after it has been cleaned. This usually will take care of the local infection in the skin and, at the next dressing, the skin around the wound will be in much better condition.

In some instances in which the disease has been diagnosed and

the bone drained relatively early, there has not been sufficient time for massive necrosis of bone to occur. The wound then will heal gradually by granulation and the drainage gradually will cease. In the majority of instances, however, so much necrosis of bone has occurred that chronic osteomyelitis will follow. This is especially true in cases of staphylococcic infection. In cases of streptococcic infection, on the other hand, there is a definite tendency for the wound to heal and for sequestration of bone not to occur. In a case in which chronic osteomyelitis is going to develop, and this is the rule, the wound will heal gradually, but a small sinus will persist and drainage from the bone will continue. At the end of from three to five months, roentgenograms may disclose sequestra. After the acute stage of the disease has passed and the wound has healed to a point at which indolent sinuses are present, the condition is one of chronic osteomyelitis, whether or not definite sequestra are visible in the roentgenogram. From this point on, the patient is treated for chronic osteomyelitis.

Other Plans of Treatment

It is to be noted that the plan of treatment outlined for acute osteomyelitis in the preceding pages is by no means the only method of treatment which is recommended in the literature. As a matter of fact, a considerable percentage of the more recent papers devoted to the treatment of this condition emphasize the general infection and tend to ignore, or deal lightly with, the local disease. The authors who adopt this attitude state that at the present time the trend in treatment is toward conservatism and they believe that the patients should wait in the hospital until the optimal time for surgical intervention. This, of course, is true, but how long should they wait and when is the optimal time for surgical intervention? Some authors even advise waiting until the temperature is normal; that is, until the patient's resistance has established an equilibrium with the infection and until there is no longer any danger of spreading the infection. Then the large extra-osseous abscess which has formed is opened by a small, so-called medical, incision. Some immobilize the limb in a plaster-of-paris cast and do not operate at all.

Advantages of Early Operation

It is my opinion that the operation should not be delayed any longer than the condition of the patient demands, as I believe that delay in drainage of the bone tends to increase the amount of destruction of the bone, to increase the danger of involvement of joints

and to increase the number of metastatic foci. I do not believe that early operation tends to precipitate fatal septicemia, provided the operation is properly performed. The advent of the sulfonamide drugs does not alter this opinion, because the bacteriostatic action of these drugs is inhibited by pus and they cannot be depended on to sterilize the local lesion in the bone.

THE DISEASE AS IT AFFECTS INFANTS

Largely as the result of observations of Green and Shannon, I have been impressed with the fact that among children less than two years of age the disease presents a very different problem from that which it presents among children more than two years of age and among adolescents and adults. Green and Shannon reviewed a series of ninety-five cases of osteomyelitis in which the patients were less than two years of age.

As would be expected, the factor of trauma was not important; there was a history of trauma in only sixteen of the cases. There was relatively little difference in the frequency of the disease between boys and girls. The disease affected most often the larger long bones; that is, the femur, tibia and humerus (Fig. 63). It tended to be juxta-epiphyseal in origin, nearly always beginning in the metaphysis and favoring the epiphysis, where growth is most rapid.

The bacteriologic characteristics of the disease as it affects infants are markedly different from those manifested when the patients are older children. In 63 per cent of Green and Shannon's cases, in which cultures were made, a hemolytic streptococcus was isolated; staphylococci were found in only 30 per cent. Among adults and older children, in about 90 per cent of the cases the infecting organisms are staphylococci. It is further to be noted that antecedent infection was noted in 55 per cent of Green and Shannon's cases. In twenty-eight of the fifty-two cases in which antecedent infection was noted it was an infection of the respiratory tract and, in these cases, the disease was due to streptococci. In the thirteen cases in which cutaneous lesions were the site of the antecedent infection, on the other hand, the disease was more frequently due to staphylococci.

In forty-eight cases in which steptococci were obtained, the mortality rate was 20 per cent, while in twenty-two cases in which a culture of staphylococci was obtained, the mortality rate was 32 per cent. Of infants less than six months of age, the mortality among ten with streptococcic infection was 60 per cent and of five with staphylococcic infection was 40 per cent. The foregoing statistics

of mortality suggest that very young infants have relatively little resistance to streptococci, but that this is acquired as the individual grows older.

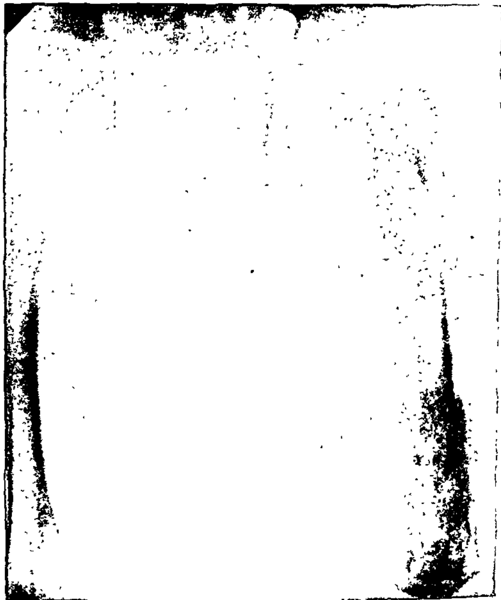


Fig. 63—Severe osteomyelitis in the femur of an infant (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

Blood cultures were made in twenty-four cases; ten of these yielded streptococci and seven staphylococci.

The symptoms of infants are similar to those of older children, the disease varying considerably in its severity. However, among infants the diagnosis and localization of the disease are consider-

ably more difficult because the patient is not able to cooperate in taking of the history and in the examination. On the other hand, among infants the swelling seems to appear more rapidly and the edema is more widespread; not infrequently an entire extremity is involved from an infection of one bone. Sepsis of the joints and separation of the epiphysis are believed to occur more frequently than among older children.

The observations of Green and Shannon show that among infants sequestration is relatively rare and that abscesses form and perforate the periosteum relatively quickly. These phenomena are explained by two factors. One is that in a considerable percentage of the cases, 63 per cent in Green and Shannon's series, the infecting organism was a streptococcus and, as has been stated previously, streptococcic infection of bone tends not to form sequestra, certainly not with the same regularity as does staphylococcic infection. The other factor is that the bone of infants is more cancellous than is that of older children and adults. The haversian and nutrient canals of young children, even of the cortical bone, are unusually wide and the cortex is thin, and this is especially true of the cortex of the metaphyses. Consequently, the compact bone of infants acts as does the cancellous bone of older children and adults. As has been stated previously, such bone rarely undergoes sequestration, and even when it is killed by the toxins of the invading organisms the trabeculae may be absorbed. Green and Shannon expressed the opinion that this absorption occurs by autolysis and that the osteoclasts play a relatively slight part. I believe that it is due to the cells of infected granulation tissue. At any rate, what bone is killed tends to be absorbed and to be replaced by living bone which is formed with unusual rapidity. Owing to the rapidity of absorption of the dead bone and to the formation of new bone, there is a marked tendency on the part of the disease of infants to be relatively short in duration. The average time for healing to occur in all cases except three of the series of Green and Shannon was eight-and-a-half weeks. If these three are added, making fifty-six cases in all in which the patients were followed, the average time of healing was twelve weeks and in thirty-one of these fifty-six cases healing was complete at the end of two months.

In the cases reported by Green and Shannon the complications were the same as those which occur among older children; that is, the most frequent complication was involvement of other bones, which occurred in twelve cases, and sepsis of joints, which occurred in eleven cases. Necropsy was performed in ten of the twenty cases

in which the patients died. With one exception, septicemia was demonstrable in these cases. Multiple abscesses were present in all of the cases and the liver, heart, lungs and skin usually were involved.

In following up the patients, it was possible to re-examine forty-one. Of these, in thirty-nine cases the lesions were entirely healed. One of the two patients whose lesions were not healed had multiple lesions, with involvement of the neck of the femur, ilium and fibula. In the other case healing had taken place but the roentgenogram gave evidence of probable quiescent infection of the bone. It is thus evident that the prognosis of the disease among infants is different from that when the patients are older children because, among infants, not only is there a tendency to prompt healing but the healing tends to be permanent.

Treatment

From what has just been said, it is obvious that infection of the bone of infants can make its exit with relatively little difficulty and with considerable promptness. Consequently, there is not the same mechanical walling off of the disease that occurs among older children and adults. Not only does the infection reach the space beneath the periosteum promptly, but the periosteum, being loosely attached, is quickly stripped up over a relatively greater distance than occurs among older children. Moreover, after the periosteum has ruptured, the abscess seeks the surface relatively quickly.

As a result, there does not appear to be the same urgency for surgical drainage of the bone among infants as obtains among older children or adults. Likewise, since there is a very slight tendency to the formation of sequestra there does not seem to be the same justification for opening the bone, even after the abscess is drained. Green and Shannon expressed the opinion, and I concur in their belief, that in the case of infants there is no great need for early operation. They found that in cases in which the operation was delayed, the patients seemed to progress just as well as, or perhaps even better than, did those who were operated on early and the bone opened. Reason for delaying the operation might be (1) difficulty in localizing the site of the disease; (2) the child might have appeared to be too ill to withstand surgical operation; (3) in cases encountered in recent years deliberate choice of the surgeon

Consequently, among infants, to a greater extent than among children and adults, the first consideration is the treatment of the patient as a whole. He should be given a full dose (depending on his weight) of *sulfathiazole* or *sulfadiazine* on admission and chemo-

therapy should be continued as long as the temperature remains elevated. If the patient is severely ill the limb should be immobilized by traction, by a splint, by a plaster-of-paris cast or, frequently, by a large, hot, wet dressing. This is done in an attempt to localize the infection, and the patient's general condition should be taken into consideration. Fluid balance should be restored and the patient should be given rest with sedative agents. It has been the experience of many observers that under such treatment, in a considerable majority of cases, the patient's general condition tends to improve and the temperature tends to fall. During this period the infection will penetrate the cortex of the bone, pus will collect beneath the periosteum, the periosteum probably will be ruptured and an abscess will appear.

As soon as the patient's general condition is sufficiently improved to permit of operation without danger, this abscess can be drained by incision of the soft tissues. When this is done, however, the patient should not be subjected to needless operation in attempting to drain the bone. Apparently, among infants, it makes little difference whether the bone is drained or not and, even without drainage, sequestration does not tend to occur and healing tends to occur promptly.

In cases in which infants are not so acutely ill and the site of the infection can be localized at the time of admission, operation is permissible and probably should be done. The operation should be carried out with precision and dispatch, and the duration of anesthesia should be as short as can be arranged. The periosteum should be split if an abscess is not found outside of the periosteum, but no attempt should be made to open the bone. Green and Shannon noted that in certain instances mild infections among infants take care of themselves if the limb is immobilized and they said that *definite* infection of bone may heal spontaneously without formation of abscess. I, too, have seen this occur, but I do not believe that it should be expected. I think it is advisable to drain the infected region as soon as the patient is in condition for the operation and as soon as the region of infection can be definitely located.

In cases of infection about the hip joint which may involve the articulation, the upper end of the femur or the adjacent portions of the pelvis, it frequently is impossible to locate the site of the disease. Consequently, the patients should be treated by immobilization, by traction, or by a plaster-of-paris cast until an abscess forms which can be drained by an incision into the soft tissues, or until the roentgenogram shows the site of the infection in the bone. As

a rule, roentgenologic signs can be seen in about a week, for the roentgenologic changes are noted more quickly when the patients are infants than when they are older children or adults.

After the operation has been completed, the wound is sprinkled with crystals of *sulfathiazole* or *sulfadiazine* and is packed open loosely with vaseline gauze. The extremity is then immobilized in a plaster-of-paris cast or in a splint, with or without traction. As a rule, the dressing should be changed in about a week or ten days, as the wounds tend to heal very rapidly. When the dressings are changed, the skin should be cleaned, covered with zinc-oxide ointment, and sulfathiazole or sulfadiazine crystals should be sprinkled in the wound, which then should be repacked loosely with vaseline gauze.

Just as in cases in which the patients are older children or adults, sulfathiazole should be given as soon as possible after the tentative diagnosis of osteomyelitis has been made and administration of the drug should be continued as long as the patient is febrile. The dose given should be a full one, depending on the weight of the patient.

In cases in which sulfathiazole is not available and the disease has been preceded by a respiratory infection, it is highly probable that the offending organisms are streptococci. Consequently, full doses of sulfanilamide or sulfapyridine may be administered immediately, even without waiting for a culture. In cases in which the infection is preceded by infection of the skin or by trauma, it is probably better not to use sulfanilamide, as the disease is probably due to staphylococci, and it is believed that in staphylococcus infections the use of sulfanilamide and sulfapyridine may actually do harm.

THE DISEASE AS IT AFFECTS ADULTS

As has been noted previously, acute hematogenous osteomyelitis is primarily a disease of childhood and is relatively rare after the epiphyseal lines have closed. However, it may occur among adults and, when it does, it is somewhat modified by the differences in structure between the bones of adults and those of children, and also by the fact that adults have somewhat more resistance to staphylococcic infection than have children. Zadek recently reported nine cases of hematogenous osteomyelitis in which the patients were adults and he emphasized that the pain is usually not well localized in the beginning but that it occurs with increasing intensity; that the onset is gradual; that the temperature is, as a rule, only moderately elevated; that preceding trauma is unusual; that the roentgenographic findings are negative until several weeks, or even months, have passed; that the method of extension is not through the haver-

sian system, and that no subperiosteal abscess is formed. He also said that the disease may begin in any part of the bone and that there is not the same tendency for it to begin in the metaphysis as there is in cases in which it affects children.

This experience is somewhat at variance with mine, because I have seen cases in which the disease among adults was fulminating, with acute onset, severe toxemia, high temperature, marked leu-



Fig. 64.—Early osteomyelitis in the tibia of an adult; duration, about one month (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

kocytosis and extensive involvement of the bone and in which even death occurred. On the other hand, I have seen other cases in which the disease was relatively mild. The same is true in the case of children; that is, there is a marked variation in severity of the disease. In cases in which the patients are adults and there is no evidence of syphilis, a local point of tenderness and severe pain over a long bone suggest osteomyelitis. This is true even when the roentgenologic findings are negative, whether or not there is evidence of preced-

ing injury and whether or not there is considerable fever and leukocytosis.

Frequently, however, the diagnosis is not made until roentgenologic examination gives some evidence of disease. The roentgenographic evidence depends on the duration of the disease and is slower



Fig. 65.—Roentgenograms made in the same case as that represented in Fig. 64, but three weeks later. There is evidence of increased destruction (Key in Lewis' Practice of Surgery. W. F. Prior Co., Inc.).

in appearing among adults than among children. This is due to the fact that the bones of adults are more dense than those of children; therefore, more extensive destruction must occur before the disease can be recognized in the roentgenogram (Figs. 64, 65). Just as among children, two types of roentgenographic change may

be noted. One is a destructive change which is indicated by spotty atrophy or rarefactions of the bone in the diseased region. The other is a productive change which is indicated by the deposition of new bone beneath the periosteum. In certain instances, this new bone may be laid down in lamellae and may suggest an endothelioma (Ewing's tumor). The leukocyte count is usually elevated to 10,000 or 15,000, and there is nearly always a slight increase in temperature. However, the temperature may be markedly elevated (103° F. or more). Toxemia usually is not very severe. On the other hand, in certain instances it is severe. As a rule, there is only one focus of the disease, and metastatic involvement of other bones does not tend to occur.

Treatment

In a case in which the patient is an adult, the picture is similar to that described and if well localized tenderness and pain persist and tend to increase as the days pass, exploratory operation is justified and advisable. The patient should be admitted to the hospital a day or two before operation and given a full dose of sulfathiazole or sulfadiazine on admission. Administration of the drug should be continued for some time after the operation, unless toxic reactions occur. At the time of the operation the bone at the point of greatest tenderness should be exposed. One will probably find some pus either beneath the periosteum or external to it. Whether or not pus is found, the bone should be opened, as it is probable that the disease will also be present in the cancellous metaphysis or in the medullary canal, even though there may be no definite necrosis of the shaft and no pus may exude from the bare bone after the periosteum has been stripped. The cortex may be drilled, but it is usually advisable to increase the size of the opening so that a window is made, the size of the window depending on the extent of the subcortical involvement.

After the operation, which is one for drainage, just as in the case of children, and not an attempt to remove all of the diseased bone, the wound should be sprinkled with sulfathiazole, packed loosely with vaseline gauze and the limb immobilized in a plaster-of-paris cast, just as was described previously in the treatment of acute osteomyelitis affecting children. Judging from Zadek's report, it is probable that sequestration will not occur and that recovery will be uninterrupted, with prompt fall in temperature and gradual healing of the wound. In some cases, however, there may be a fulminating infection or there may be a diffuse infection of the bone with eventual necrosis and sequestration of a considerable portion.



CHAPTER XVI

LOCALIZED HEMATOGENOUS OSTEOMYELITIS

THIS is a condition in which organisms are carried into the bone by the blood stream but the bacteria are not sufficiently virulent to cause an acute, diffuse infection. It is probable that in many instances the condition begins as a minute, localized infection which is walled off by the tissues and the organisms just manage to hold their own for a considerable time. However, as they persist they gradually cause destruction of a certain amount of bone, although the amount is usually small, and incite a proliferative reaction in the surrounding bone. In other instances the disease begins moderately acutely, with slight fever, moderate pain and some redness and tenderness in the region. However, it does not tend to spread and cause severe illness, such as is characteristic of acute diffuse osteomyelitis. The condition may be primary or it may be secondary to acute or chronic osteomyelitis elsewhere.

Probably in many cases of acute osteomyelitis localized abscesses develop in other bones of the body and are never heard from. Phemister[19, 21] has reported a number of cases in which development of the metastatic abscess caused no symptoms whatever and the lesion was discovered only some months later when it caused pain or other symptoms; at that time there was a well developed abscess with considerable reaction in the surrounding bone. As a rule, however, the local abscesses which occur as metastatic lesions in cases of acute or chronic osteomyelitis tend to give rise to symptoms, although they do not have the same tendency to spread as does the original infection. On the other hand, the local abscess of bone may affect an apparently normal individual who has never had osteomyelitis or any other chronic pyogenic infection. In these instances it is common to term these abscesses *Brodie's abscesses,* because they were first described by Brodie. As a matter of fact, it is not uncommon to find all types of chronic, local, inflammatory lesions of bone which are not due to some specific disease described as Brodie's abscess, whether or not they contain pus and whether or not a positive culture is obtained when the lesion is exposed.

progressed very slowly, or which may have been present for many months or years before it caused symptoms, may be surrounded by a wide, dense zone of eburnated bone.

If the abscess is sufficiently close to the surface of the bone there is a definite periosteal reaction over it, with subperiosteal formation of new bone which results in thickening of the cortex. In certain instances this subperiosteal reaction has been going on for a long period and there may be marked thickening of the bone,



Fig 66.—Osteoid osteoma near the posterior portion of the cortex of the tibia. *Left*, preoperative view; *right*, postoperative view. The wound was sutured at the time of operation and remained closed (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

so that it is considerably enlarged. In instances in which the abscess borders on the medullary canal there may be a reaction of the endosteum so that the medullary canal may be encroached on or even entirely obliterated. The contents of the cavity vary considerably and range from frank pus which contains large numbers of organisms to fibrous or osteoid tissue which is sterile on culture. The abscesses which are secondary to osteomyelitis as a rule contain pus. The abscesses which are spontaneous and hematogenous in origin, so-called

With the exception of the silent abscesses of bone, such as those described by Phemister, a typical abscess of bone which occurs as a metastatic lesion in a case of osteomyelitis tends to begin as a moderately acute inflammatory disease of the bone. Pus forms relatively soon, and the destruction of bone is relatively rapid. Then the typical abscess that has just been referred to forms in the bone and in the soft tissues and the course resembles that of mild hematogenous osteomyelitis. As a rule, these abscesses either open spontaneously or are drained surgically.

A typical Brodie's abscess, on the other hand, tends to begin insidiously and is probably well advanced before symptoms occur. It tends to be localized in the metaphysis near the epiphyseal line, just as does the lesion of acute, diffuse osteomyelitis in the early stages, and its localization is probably caused by the same factors as those which cause the metaphyseal localization in the acute disease. The most frequent site is the lower end of the tibia. The earliest symptom is pain, which may be present intermittently for weeks or months. There is a history of trauma in a considerable percentage of cases, and it is probable that the trauma is a factor in the localization of the disease. The pain usually is not severe at first but it tends to increase in intensity and to be worse at night. Eventually, if the bone is sufficiently near the skin, swelling may be palpable and visible.

As the disease continues there may occur exacerbations of the symptoms from the Brodie's abscess in which there may be slight fever, mild leukocytosis, mild reddening and local increase in the temperature of the soft tissues over the site of the lesion. Occasionally, purulent material may escape into the subperiosteal region of the bone or even into the soft tissues. With rest, the symptoms tend to quiet down.

The diagnosis of Brodie's abscess usually is made from the roentgenogram. This discloses an area of rarefaction in the cancellous bone, surrounded by bone which is more dense than normal. As a rule, the area of rarefaction which represents the abscess is relatively small; rarely is it more than 1.5 to 2 cm. in diameter. The area of sclerotic bone around it varies considerably in thickness and it is believed that this variation depends somewhat on the period of time during which the infection has been present in the bone. Given an abscess which has been present for a relatively short period, and in which the destruction of bone has occurred rather rapidly, there has not been sufficient time for much building up of eburnated bone around it. An abscess which is known to have been present a long time, and which has

difficult of access, or if the surgeon is inexperienced, it is probable that opening by drill holes should be recommended. The same is true of certain abscesses which are close to the articular surface of the joint, and it is noted that in the presence of abscesses of this type it is frequently the articular symptoms which predominate; the patient may be treated for rheumatism or arthritis for months before the abscess is discovered.

After the overlying, dense sclerotic bone has been chiseled away and the abscess has been exposed, further treatment can be decided on, depending on the character of the contents of the abscess. If the abscess contains pus or liquid which is probably infected, the pyogenic membrane which lines the abscess should be removed, the walls of the abscess should be subjected to saucerization, crystals of sulfathiazole should be sprinkled in the wound, and the wound should be closed without drainage or with a small rubber drain or strip of vaseline gauze extending down to the bone. If the abscess contains granulation tissue or osteoid tissue, this can be excised and the wound sprinkled with sulfathiazole and closed without drainage. As a rule, these wounds should heal without complications and the period of disability should be relatively short. If the abscesses are treated as suggested, it is believed that there will be relatively little tendency for them to recur.

Brodie's abscesses, sometimes contain pus; sometimes contain yellowish fluid which, in turn, contains flakes of fibrin; sometimes contain granulation tissue; sometimes contain fibrous tissue, and sometimes contain osteoid tissue.

It is possible that the condition recently described by Jaffe as osteoid osteoma (Fig. 66) is really a low-grade infection of bone in which either pus never has been present or the infection gradually has disappeared and the cavity has been replaced by osteoid tissue. In the abscesses or cavities which contain pus or fluid of any sort, the abscess cavity is lined by a definite pyogenic membrane. When the cavity is opened and this membrane is removed with a curet, it is found to rest on a layer of dense, eburnated bone. In instances in which the cavity is filled with soft tissue, granulation tissue, fibrous tissue or osteoid tissue, the culture is usually sterile. When pus is present the culture usually yields a Staphylococcus aureus. The thin, yellowish liquid, containing fibrin which may occupy the cavity, may yield attenuated staphylococci on culture. Similar abscesses have been reported which have yielded typhoid bacilli on culture.

TREATMENT

The treatment of localized osteomyelitis is surgical and the operation should be done when convenient for the patient and the surgeon. There is no urgency about the operation. The patient should be hospitalized for two days before the operation and given full doses of sulfathiazole or sulfadiazine, depending on his weight. Administration of the drug should be continued for several days after the operation. At the operation, the bone is exposed through the most direct route and the abscess is treated according to the character of the infection present. If there is evidence of acute infection, or if pus is encountered, I believe that the abscess should be excised if possible. This is in spite of the fact that Brickner and other authors have said that practically all local infections of bone can be cured by opening the cavity with a small drill and then sewing the wound up tight, except for a rubber tissue drain which extends down to the surface of the bone. I do not believe that this is adequate treatment in cases in which pathogenic cocci are present in the tissues, nor would I expect such a cavity to close after merely having been opened by a drill hole.

Since the patients are not very ill and as there is no reason why a complete surgical operation should not be done, there does not seem to be any valid objection either to excising the abscess or performing saucerization. When the abscess is deep in the bone and is

difficult of access, or if the surgeon is inexperienced, it is probable that opening by drill holes should be recommended. The same is true of certain abscesses which are close to the articular surface of the joint, and it is noted that in the presence of abscesses of this type it is frequently the articular symptoms which predominate; the patient may be treated for rheumatism or arthritis for months before the abscess is discovered.

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CHAPTER XVII

CHRONIC DIFFUSE HEMATOGENOUS OSTEOMYELITIS

SCLEROSING OSTEOMYELITIS OF GARRÉ

THIS is a relatively rare disease which tends to occur in the shaft of the long bones and which was described by Garré as "sclerosing ostomyelitis." In the cases reported by Garré, the onset was acute, with high fever, pain and swelling in the majority of cases, but the acute inflammation subsided without formation of abscess and a sinus, leaving a thickened, sclerotic region in the bone. This might remain dormant for a variable length of time and then become painful again; it might even cause local signs of inflammation (warmth, redness, tenderness and swelling).

It is this chronic stage of the disease which is spoken of as Garré's "sclerosing osteomyelitis." In some cases the onset appears to have been slow and insidious. In others there was a preceding acute stage, which subsided. Often the history was vague and indefinite.

In the chronic stage, with a flare-up of symptoms the earliest symptom is pain. The pain is dull, is aggravated by activity and is relieved with rest. The pain tends to be more marked at night, just as is true in cases of localized abscess of bone and in cases of syphilis of bone. There may be slight fever and general malaise plus local signs of inflammation.

As the disease progresses there is an increase in the density of the infected bone over a region usually 3 or 4 inches (about 7.5 or 10 cm.) long. The condition tends, as a rule, to be localized in the shaft of a long bone, particularly the femur or tibia. This increase in density is due to the deposition of new bone in the haversian canals, so that these canals are largely obliterated. In addition to the increase in density of the bone there is also a deposition of new bone beneath the periosteum and at the periphery of the marrow canal. Eventually, there may be a tendency to complete obliteration of the marrow canal, although a marrow canal of small diameter

usually persists and the bone becomes thickened to a considerable degree. The diagnosis can be made from the roentgenogram, which shows the changes just described. The disease may be confused with sclerosing sarcoma of bone or with syphilis. As a rule, localized abscesses are not seen in the roentgenogram of the sclerotic bone and there appears to be a diffuse infection through the bone. In some instances, however, one or more small regions of rarefaction may be visible. These may represent abscesses or osteoid changes. The disease may persist for years and may be subject to exacerbations which quiet down with rest or for no known reason. Unless an exacerbation is present at the time of the examination, there are no general symptoms and the swelling of the bone is not tender on pressure.

Treatment

Treatment is surgical and consists of opening the bone; usually it is recommended that a portion of the dense cortex be removed and the marrow canal be exposed. Cultures taken at this time may or may not reveal staphylococci. Some surgeons recommend multiple drilling of the bone. As a rule, after either of these operations the symptoms may be expected to abate, although the spindle-like swelling of the bone will persist, except in that portion removed by the operation. However, there are exceptions to the cure by operation. One of these occurred in a case in which I drilled the bone for sclerosing osteomyelitis which involved the entire shaft of the tibia of a young Negress. The disease had been present since childhood and drainage never had occurred. After the drilling, the high fever and diffuse osteomyelitis developed and involved the entire shaft of the tibia. The disease was so severe that eventually the leg was amputated at the insistence of the patient.

In view of this experience I no longer drill the sclerotic bone in these cases; rather, I excise a large section down to the marrow canal. If osteoid portions or abscesses are seen in the roentgenogram, or are encountered in the course of the operation, they are excised, or saucerization is performed and the abscesses treated as has been described previously.

It is to be noted that I have mentioned chronic abscesses of bone, chronic sclerosing osteomyelitis and the osteoid osteoma of Jaffe (Fig. 66.). It is also to be noted that the first two conditions overlap considerably, in that the chronic abscess of bone of long duration is surrounded by sclerotic bone while, in a case of sclerosing osteomyelitis there may be one or more abscess cavities (Fig. 67).

The treatment is essentially the same; excision or saucerization, and closure with or without drainage, after local implantation of sulfathiazole powder.

When the cavity is found to contain osteoid tissue the wound may be closed without drainage, for cultures of the material obtained so far have given negative results. Indeed, Jaffe expressed the opinion

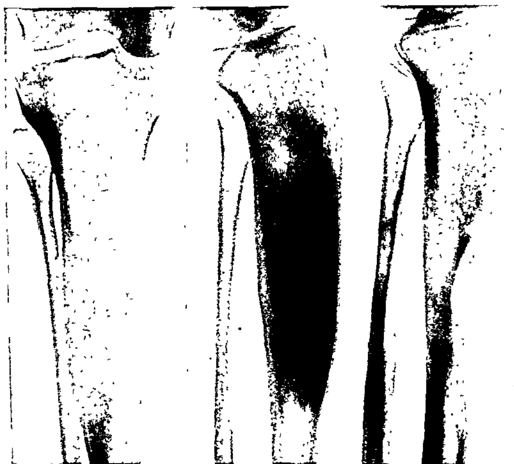


Fig. 67.—Sclerosing osteomyelitis of the tibia. *Left,* anteroposterior; *middle,* lateral; *right,* roentgenogram made after the operation. A relatively large abscess cavity was found in this bone (Key in Lewis: Practice of Surgery. W. F. Prior Co, Inc).

that osteoid osteoma is a benign neoplasm and not an inflammatory lesion. The marked sclerosis in the bone around the lesion inclines me to disagree with him and to discount his and my own negative cultures. Consequently, the disease is included in this section. However, Jaffe may be right.

Before operating on any chronic abscess of bone it is advisable

to give the patient sulfathiazole or sulfadiazine by mouth for the preceding twenty-four hours in order that the blood may contain a satisfactory concentration of the drug at the time of operation, which discourages extension of the disease. Administration of the drug should be continued for several days after the operation.

CHAPTER XVIII

SUBACUTE INFECTIONS OF BONE

OSTEOPERIOSTITIS ALBUMINOSA OF OLLIER

THIS is a chronic, low-grade infectious condition which usually arises in the periosteum or in the subperiosteal portion of bone and results in the production of a localized, indolent swelling which contains a clear or serous, stringy or mucoid exudate which resembles the white of an egg or synovial fluid. Since the fluid has a high content of albumin, this condition was called by Ollier "osteoperiostitis albuminosa." This disease is rare, but Kuth recently has collected reports of more than sixty cases from the literature and has reported four which he observed personally.

Osteoperiostitis albuminosa may begin as mild, acute osteomyelitis. Usually, however, it begins insidiously, without any local or general symptoms, the first symptom noted being tenderness or swelling. In cases reported in the literature the disease has varied in duration from approximately four days to twenty-nine years. In most of the cases, however, the swelling had been noted for more than three months. The patients complained of the swelling and of mild pain. In about a fourth of the cases there was a history of preceding trauma. On physical examination there is usually slight local warmth over the swelling, which may be fluctuant and moderately tender. The roentgenograms show swelling of the soft tissue and may give evidence of some small sequestra. These sequestra may be free in the abscess cavity, which may be large. The diagnosis is made from the character of the fluid obtained by aspiration or at operation.

At operation the swelling is incised. An albuminous, mucoid material escapes and sometimes a small sequestrum escapes with it. In other instances there is no sequestration. The cystlike mass has a fibrous wall and usually is adherent to the bone, from which it presumably arises. There appears to be considerable variation in the relation of the cystlike tumor to the bone and periosteum. It is believed that in the majority of instances it arises as a mild subperios-

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teal infection. It is possible that in some instances it begins as an infection in the periosteum, or extraperiosteally. Occasionally, it appears to arise in the cortex of the bone or in the medullary canal. There appears to be a definite relation between this condition and certain attenuated abscesses of bone or central cysts of bone which contain similar fluids in which there is flocculent material. On culture these fluids yield staphylococci.

The treatment is incision and drainage and removal of any sequestra that are present. As a rule, the wounds have been closed, after drainage of the cyst, except that a small rubber tissue drain or a vaseline gauze drain has been left in place for a few days. I would advise implantation of sulfathiazole in the wound and closure without drainage. There is relatively little danger that the attenuated infection will recur or that chronic osteomyelitis will develop.

CHAPTER XIX

TYPHOID OSTEOMYELITIS

OWING to the fact that typhoid fever has been almost eliminated by the activities of the health departments, typhoid osteomyelitis is now of very rare occurrence. As a matter of fact, I have seen only two cases and I did not operate in either one. In the literature it is stated that infection of bone develops in approximately 1 per cent of all cases of typhoid fever. It is probable that the organisms reach the bone marrow during the acute stage of the disease and that they remain dormant in the bone marrow until something causes them to begin growing.

As a rule, onset of the symptoms referable to involvement of bone is during the convalescence from the acute illness. Occasionally, however, the organisms may remain dormant for months, or even for many years, and then start growing and cause an infection of bone. As a rule, the infection in bone is subacute or chronic. Occasionally, the infection is moderately acute, with a tendency to fever and leukocytosis, and formation of an abscess.

The first symptom is pain, which at times is very severe. This is followed by tenderness and swelling. Occasionally, there may be increase in the local temperature and, if an abscess has formed, fluctuation may be present. In the presence of an acute infection the roentgenographic findings may be negative. However, as a rule, the infection is relatively slow in appearing and the roentgenogram gives evidence of some thickening of the cortical bone and perhaps of ossifying periostitis. In other instances, there will be eburnation of bone at the site of the lesion. There is relatively little tendency to destruction of bone, such as occurs in cases of pyogenic osteomyelitis. Pain in the bone, with or without swelling, and the appearance of an abscess following an attack of typhoid fever or paratyphoid fever, lead to the diagnosis. This should be confirmed by culture. In certain instances in which the disease is untreated, the lesion of bone may heal spontaneously. In other cases, an abscess may form and purulent material may continue to discharge for years. This material may contain typhoid bacilli in pure culture, may be

contaminated by pyogenic organisms, or the typhoid bacilli may disappear and the pyogenic organisms take their place. As a rule, the blood count is normal. Occasionally, the leukocyte count may reach 15,000 or 20,000 per cubic millimeter of blood in a case of acute infection with an abscess. The temperature may be normal or there may be moderate fever. The constitutional symptoms are usually mild.

The treatment of typhoid osteomyelitis varies with the type of infection encountered. In a relatively mild infection, with merely sclerosis of bone and no abscess, it is possible to excise the diseased portion, close the wound by primary suture and thus eliminate the disease. In such an instance I would be inclined to sprinkle a considerable quantity of sulfathiazole crystals in the wound before closing it. If an abscess is very large, as was the abscess of the thigh reported by Winslow, which contained about a quart (about 1000 cc.) of pus and several small sequestra, excision of the wound is out of the question. In this particular case the abscess was opened, the bare femur was found exposed in the depth of the abscess, with its periosteal tissues destroyed, and when two holes were bored in the femur pus was found in the marrow canal. Nevertheless, in spite of the fact that no effort was made to remove the diseased bone, other than the few small sequestra which were free in the abscess, the wound healed within a few months and the patient recovered, with a normally functioning leg.

If there is a sinus of long duration, it should be excised and the adjacent diseased tissue also should be excised. The disease tends especially to attack the tibia, the femur and the ribs. In typhoid infection of the ribs and costal cartilages, relatively wide excision may be necessary to effect cure. After excision of a sinus which is the site of chronic infection, it probably is wise to leave the wound open, to sprinkle it with sulfathiazole powder and to pack it with vaseline gauze; or it may be closed if the diseased tissue is fairly completely excised.

It is to be noted that living typhoid bacilli are present in the purulent material that is discharged; consequently, the patients should be isolated and a vigorous attempt should be made to clear up the disease quickly. Otherwise, the patients may serve as carriers and transmit the disease.

In operations on patients suspected of having typhoid osteomyelitis, precaution should be taken in the operating room to prevent transmission of the infection to the operating team or to others.

In about a third of the cases, more than one bone is involved,

usually only two, and in such instances all foci should be eliminated. Vaccine therapy has been used with success in a few cases. However, I believe that operation should be tried first and, if this fails, then vaccine therapy may be used in the hope that it will aid in clearing up the residual infection.

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CHAPTER XX

CHRONIC OSTEOMYELITIS

WHEN the fever caused by the acute osteomyelitis subsides, the toxicity disappears and the general condition improves, the patient enters the convalescent stage, during which the bone attempts to heal. During this period new bone is formed and any bone which is dead can be separated from the living bone. The separated, dead bone may remain as a sequestrum if it is in a sufficiently large mass that it cannot be absorbed, or it may be incorporated in the new, living bone and become surrounded by it. If the dead bone becomes incorporated in the new, the dead bone may undergo a slow process of absorption and creeping replacement. Relatively thin pieces of dead bone, such as are represented by trabeculae which are exposed to living granulation tissue, may be completely absorbed.

As a result of the disease or operative procedures, or both, there develops in the interior of the bone, usually in the metaphysis and sometimes extending into the diaphysis and marrow canal, a cavity which may be filled with infected granulation tissue and pus, or with necrotic bone and necrotic soft tissues. The growth of the new bone beneath the periosteum and from the endosteum attempts to repair this defect. As a rule, however, it is not possible for repair to take place because nature is not able to obliterate the cavity, with its rigid walls. Consequently, this cavity becomes surrounded by bone which gradually increases in density owing to deposition of new bone in the haversian canals. With the increase in density there is progressive diminution of the organic material in the bone. Consequently, its ability to resist and destroy bacterial infection is decreased. Not only is this true, but as the bone becomes more dense, and as its cellular elements become less in number, it loses its ability to heal and to form new bone.

As a result of these phenomena there develops the state of chronic osteomyelitis, in which there is a cavity in the bone lined and incompletely filled by infected granulation tissue.

The walls of this cavity are surrounded by dense, eburnated bone with relatively poor circulation, part of this bone having been



Fig. 69.—Extensive chronic osteomyelitis involving almost the entire tibia (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

formed from endosteum, part of it from the periosteum or from cells beneath the periosteum, and part of it being the original shaft. Within this cavity there may be one or more pieces of dead bone of variable size. These pieces of dead bone, or sequestra, are usually the remains of the cortex of the original bone which have been separated from the living bone (Fig. 68). They may lie loose in this cavity, which is filled by purulent material, or they may be more or less incorporated in the living bone. Sometimes they are not entirely free. As a rule, however, if they are of considerable size the sequestra become entirely separated from living bone, are surrounded by infected granulation tissue and are enclosed by a dense wall of newly formed bone which is called the "involucrum." Occasionally, these sequestra are several inches in length.



Fig. 68.—Chronic osteomyelitis of the first metatarsal bone. A small sequestrum is visible (Key in Lewis: Practice of Surgery. W. F. Prior Co, Inc).

The sequestra are visible in the roentgenogram as masses of dense bone with jagged or irregular margins. They exhibit an increased density when compared with the surrounding bone unless they have been present for a very long time and the surrounding bone has become eburnated. The sequestra are, as a rule, composed of compact bone and retain their original density, there being little or no tendency for rarefaction of dead bone to occur, once it has become separated, and very little tendency for it to be absorbed if it lies free in an abscess cavity. Such sequestra may remain in situ for many years; it is mechanically impossible for them to be extruded through the small openings (cloacae) in the involucrum which lead to the sinus tracts that drain the abscess cavity in the bone.



Fig. 71.—Chronic osteomyelitis following infection of a compound fracture. In addition to the sequestra visible in the roentgenogram, many others were found at operation (Key in Lewis Practice of Surgery. W. F. Prior Co., Inc.).

In addition to the abscess cavity, to the dense eburnated walls of the cavity, and to the cloacae or openings into the walls of the cavity which are usually formed by the involucrum or new bone, it is to



Fig. 70.—Old, chronic osteomyelitis and arthrodesis of the ankle joint; abscess in lower end of tibia (Key in Lewis. Practice of Surgery. W. F. Prior Co., Inc.).

be noted that chronic osteomyelitis is characterized by increased density of the bone for a considerable distance up and down the shaft from the frankly infected region. This increase in density is the result

which are not visible in the roentgenogram but which may be noted by the surgeon when he is operating in an attempt to cure the chronic disease.

Likewise, it is to be noted that not all sequestra are revealed in the roentgenogram. Only the larger and more dense sequestra are visible. As a rule, in operating on patients with chronic osteomyelitis for the removal of sequestra, considerably more dead bone is found than could be identified in the roentgenogram before the bone was exposed. Occasionally, the sequestra are not surrounded by the involucrum, but lie partly or completely loose in the soft tissues, having been extruded from the bone or having been separated from the bone and cast off without being surrounded. Not infrequently the end of a sequestrum may project through a relatively large opening or cloaca in the involucrum.

Figures 69, 70, 71, 72, 73 and 74 represent some of the lesions that may be encountered in cases of chronic osteomyelitis.

Chronic osteomyelitis may pursue one of three courses: 1. The sinuses and cavities may persist indefinitely for months or even for years. 2. The drainage may cease, the sinus may close, the infection may remain quiescent in the bone and never be evident again, or it may light up and cause an acute disease at any time. 3. One or more sequestra may be discharged spontaneously through the sinus and then the lesion may heal and remain healed. Occasionally, even in the presence of a draining sinus, the infection may be walled off in some other portion of the bone and may flare up and cause acute disease. Again, the infection may have been present in the interior of the bone for a prolonged period without apparent activity and may become active and cause acute disease.

As a rule, the acute flare-ups of chronic osteomyelitis are not so severe as is acute hematogenous osteomyelitis. The toxemia does not become so severe, the temperature does not go so high and there is not so much danger of infection of the blood stream. Sometimes, however, the flare-up may be very severe, the toxemia may become very serious, marked symptoms may develop and the patient may even die as a result of a flare-up of chronic osteomyelitis which has been present for twenty years or more. This is further evidence that, in a case of osteomyelitis, although it may be mildly active for a prolonged period, adequate immunity to staphylococcic infection does not develop and the patients are unable to combat an infection of the blood stream if conditions arise which permit the organisms to find their way into the general circulation.



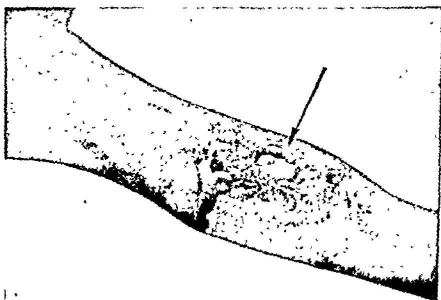


Fig. 72.—Chronic osteomyelitis similar to that represented in Fig. 71. The tibia is exposed (Key and Conwell).

of infection and not infrequently such bone contains minute portions of walled-off, infected granulation tissue. It may contain abscesses



Fig. 74.—Roentgenogram made following resection of the tibia in the same case as that represented in Fig. 73 A disklike sequestrum is visible. The wound healed after this was picked out Amputation was performed later because the patient was unable to bear her weight on the limb (Key in Lewis: Practice of Surgery. W. F. Prior Co, Inc).

TREATMENT

There are two aspects of the treatment of chronic osteomyelitis. One is treatment of an acute flare-up of the disease and the other is treatment directed at the eradication and permanent cure of the disease.



Fig 73.—Chronic osteomyelitis. Patient was a woman, aged twenty years The disease had begun in the tibia when she was a child, drainage never had occurred. *Left,* roentgenogram made before operation; *middle,* after multiple drill holes had been made; *right,* after saucerization, which was performed because a drilling operation had been followed by a severe infection throughout the bone (Key in Lewis· Practice of Surgery. W. F. Prior Co., Inc.).



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There are two aspects of the treatment of chronic osteomyelitis. One is treatment of an acute flare-up of the disease and the other is treatment directed at the eradication and permanent cure of the disease.

Preliminary Surgery

In an acute flare-up of the disease, with formation of abscess, elevated temperature, toxemia, local pain and swelling and other symptoms of acute pyogenic infection, the patient is given full doses of *sulfathiazole* or *sulfadiazine,* depending on his weight, the fluid balance is restored and the patient is given rest and is put in condition for the operation, just as is done in the treatment for acute hematogenous osteomyelitis. The treatment is then directed toward adequate drainage of the infected region. The bone is exposed through the most direct route and the extra-osseous abscess, if present, is opened. If an abscess is not present, the bone is drilled or a window is made in the cortex of the bone and the purulent material is permitted to escape. It is to be emphasized that the object of this operation is not removal of dead bone or an attempt to cure the chronic disease. This is merely an attempt to drain the focus of infection in the bone. The abscess is drained as quickly as possible and with as little disturbance to the patient as possible, and the general treatment of the infection is carried out just as has been described under *treatment of acute osteomyelitis. As a rule, the extremity is im*mobilized in a plaster-of-paris cast or splint to aid in combating the infection. Chemotherapy is continued until the temperature subsides and the patient's general condition improves, but it is not continued indefinitely in an attempt to sterilize the chronically infected bone.

The treatment of chronic osteomyelitis is largely surgical, as I know of no medication or vaccine, toxoid, or antitoxin which has any effect on the course of the disease. On the other hand, the radical operative treatment of this condition is an elective procedure and should be done when the patient is in good general condition. In other words, surgical cure should not be attempted during an acute flare-up of the infection in the bone or in the scar tissue in the vicinity of the bone. Depending on the size of the bone and the extent of the osteomyelitis, the operation may be a relatively minor procedure or it may be a major procedure. In case a major procedure is contemplated, the patient should be put in as good general condition as is possible before the operation.

If the general condition of the patient is poor, a radical operation should not be attempted, but one or more relatively minor operations may be indicated for more adequate drainage. Usually, these should be followed by immobilization in a plaster-of-paris cast, or immobilization alone may be sufficient to tip the scale in favor of the patient and to result in improvement in his general condition.

Fresh air, sunshine and rest, and a generous diet containing ample vitamins are used when indicated. In certain instances, repeated transfusions of whole blood are given in order to improve the patient's general condition and increase the chances of effecting permanent cure of the disease.

Definitive Surgery

Before the operation, roentgenograms of the affected bone should be made in two planes and the surgeon should, by studying these, plan in as much detail as possible just what he is going to do. A day or two before the operation, administration of full doses of sulfathiazole or sulfadiazine, depending on the patient's weight, is started and this is continued for several days after the operation, until success or failure can be determined.

Since the patient is not acutely ill, the limb is prepared for the operation in the usual way by shaving and scrubbing the skin and painting it with a cutaneous antiseptic agent. Then the patient is given general anesthesia and, if it is possible to use one, a tourniquet is applied after the limb has been drained of blood. The limb is then draped in such a manner that it may be freely movable. An incision of adequate length is so planned that the infected portion of the bone will be exposed. This incision is carried directly down to the bone, avoiding as much as possible important structures. Any vessels of considerable size which are encountered in making the incision and exposing the bone are ligated immediately, as they will bleed after the tourniquet has been removed. For ligation, number 0 plain catgut is used.

When the bone is reached, the periosteum is incised longitudinally over the infected region. Sometimes the incision will follow and include a sinus tract and sometimes the sinus tract will not be in the vicinity. If the sinus tracts do not happen to be where the surgeon thinks the incision should be made, they may be excised. After the periosteum has been incised for a variable distance, depending on the extent of the disease, it is stripped up on each side for a distance of from ½ to 1 inch (1.25 to 2.5 cm.) or more, depending on the size of the bone and the amount of cortex that it is advisable to remove. This stripping up of the periosteum will expose the cloacae or openings into the cavity in the bone, if such exist. Then a relatively wide region of the cortex around the entrance into the bone is outlined with the corner of a relatively heavy but very sharp osteotome. Usually this large piece of bone is removed in one piece to form a window. However, if the surgeon is not experienced in

operating on the relatively brittle, extremely dense bone which is frequently encountered, he may use multiple drill holes to outline the window or may chip off the bone piecemeal, because in removing it in large fragments it is necessary that very sharp osteotomes or chisels be used and that they be driven into the bone only a short distance at a time; otherwise, a pathologic fracture may be caused. The large, oval piece of bone is usually 3 or 4 inches (about 7.5 or 10 cm.) long and from ¼ to ½ inch (0.6 to 1.25 cm.) thick. The thick portion is mostly eburnated involucrum.

Construction of the large window usually reveals a cavity which is filled with infected granulation tissue and which contains one or more sequestra. If any sequestra are encountered they are removed. Very long sequestra may be cut across and each end pulled out separately. Then the extent of the cavity up and down the bone is explored gently, care being taken not to increase its size. After its extent has been determined, more bone, if necessary, is removed until *the entire outer covering of the cavity on one side is removed.* In instances in which the cavity extends toward the adjacent joint, beyond the attachment of synovial membrane, it is improper to remove the entire outer wall as special care should be taken not to enter joints in operations for chronic osteomyelitis.

After the cavity has been well exposed, its contents are cleared out by removing them gently with a curet or gouge and the bony walls of the cavity are exposed by removing its pyogenic membrane. Sometimes it will be found that these cavities extend into cancellous bone and that the cancellous bone adjacent to them is necrotic. This necrotic bone should, when possible, be removed if it does not leave too large a cavity with overhanging edges. However, doubtful cancellous bone should be left in place as large, deep cavities near the ends of bones cannot be saucerized.

After the cavity has been well cleared out and extensions of the infection into recesses jutting out from the lumen of the cavity have been removed, more of the thick cortical bone should be removed in an attempt to saucerize the cavity. "Saucerization" is the term applied to the operation, the object of which is so to shape the walls of the cavity that they will have a gentle slope toward the central portion, thus permitting the soft tissues over the bone to fall into the cavity or grow into the cavity and obliterate it. After the entire infected region has been thoroughly explored, all possible infected and loose tissue is removed and especial care is taken not to remove any living bone unnecessarily.

Then the tourniquet is removed and the hemorrhage is controlled.

Usually, it will be found that some vessels of considerable size have not been ligated and will bleed. These are ligated with catgut and, if necessary, with a ligature on a needle, as it is difficult to tie the ends of vessels embedded in dense scar tissue. It also may be found that the bone bleeds considerably. Sometimes it will be necessary to pack the bone with dry gauze in order to control the hemorrhage. Usually, however, the bleeding from the bone is not sufficient to cause much difficulty. The wound is made as dry as possible and the entire cavity is sprinkled rather generously with crystals of sulfathiazole. Then gauze, which is heavily impregnated with vaseline, is placed in the cavity. The gauze is placed in such a manner that the dead spaces are filled, that it can be removed without undue force and that it will not plug the cavity and prevent drainage. In other words, the vaseline gauze pack should be relatively loose.

In many instances the wound is partially sutured, using through-and-through sutures of silkworm gut, beginning at either end and suturing toward the middle, leaving little strips of vaseline gauze extending into the cavity in the bone and projecting at this point. In this way a relatively large wound can be transformed into a relatively small one and later healing can be accelerated without seriously interfering with adequate drainage. A dry gauze dressing is then placed over the vaseline gauze which projects from the wound and a firm bandage is applied (usually what is known as a heavy gauze roll). The extremity is then wrapped with sheet cotton and immobilized in a neutral position in a plaster-of-paris cast, the cast being so applied that the joints above and below the infected region are fixed.

The cast is not disturbed for from one to four weeks, depending on the postoperative course. As a rule, however, after about one or two weeks there has been considerable drainage from the wound and it is advisable either to cut a large window in the cast, remove the vaseline gauze pack and place a smaller one in the wound or, better still, to remove the entire cast, carefully dress the wound, remove the sutures which usually will be found to be mildly infected, and reapply a cast.

The patient can be sent home wearing the second cast and need not return to the hospital until he is ready for a change of plaster, as a rule, at the end of about four weeks. At the application of the second cast, more sulfanilamide or sulfathiazole is sprinkled into the wound before the vaseline gauze is placed there. Crystals of sulfanilamide or sulfathiazole do not sterilize the wound but they do tend to lessen the amount of infection. In my opinion they do not interfere with the healing of the wound. It is possible that, by decreasing the

rate of growth of the bacteria, they may also favorably influence healing of the wound and that, if sulfanilamide or sulfathiazole is used, certain operations may result in cure of the disease which would have failed had the drug not been used.

If the operation has been adequate—that is, if all dead and infected bone has been removed—and if mechanical conditions for healing by the soft tissues have been created, then it may be expected that the wound will become progressively smaller, that the amount of material which drains forth will become progressively less and that the wound will heal. The period of time necessary for healing depends on the size of the wound and on the virulence of the infection, as well as on the nature of the soft tissues around the wound. Wounds in dense scar tissue and bones near the surface tend to heal more slowly than do bones well covered by relatively normal soft tissue. During the process of healing new bone will be formed, not only by the periosteum which has been stripped up, but also by the bone which comprises the wall of the cavity, so that there will be a tendency toward progressive increase in the size of the bone and progressive obliteration of the cavity.

In instances in which saucerization has required removal of a considerable portion of bone and the bone that has been left is relatively thin and weak, especial care should be taken not only to protect the limb from postoperative fracture by use of plaster of paris, but also to see that the limb is not fractured by undue rough handling or strain during the subsequent application of dressings, until ample time has elapsed for new bone to form and become strong, thus creating sufficient strength to bear the strain. Likewise, weight bearing should not be permitted without support until roentgenologic examination discloses what is judged to be sufficient bone to support the weight of the body.

In certain instances, when any cast is changed it will be found that discharge from the wound has spread out over the skin and has caused more or less severe infection of the skin. This is in spite of the fact that the skin around the wound may have been covered with vaseline gauze before the dry dressing was applied. If the skin is found to be red and irritated, and if it contains pustules at the time of the dressing, the pustules should be opened and the skin washed thoroughly with alcohol and then covered with a heavy layer of zinc oxide ointment. This ointment may extend to the edges of the wound. Then the vaseline gauze is applied and the cast is put on as usual. In the subsequent application of dressings, the same process is repeated as often as is necessary. At times I mix iodoform gauze with

the vaseline gauze in order to keep down, or modify, the odor of the discharge from the wound.

The treatment described in the foregoing, known as the "Orr treatment," is the form I generally use, unless it is possible to suture the wound after the operation on the bone has been completed.

Maggot Treatment

This was introduced by William S. Baer shortly after the war of 1914–1918. Owing to his enthusiasm it enjoyed a considerably wide use for several years and is still used in a few clinics. It is claimed that the maggots remove devitalized tissue which offers favorable media for bacterial growth, that they digest the bacteria, that the alkaline excreta of maggots is detrimental to the growth of the pathogenic organisms and that the maggots excrete a substance (allantoin) which stimulates the development of granulation tissue and causes the wounds to heal more promptly and with less scar tissue than otherwise.

In using the maggot treatment a saucerization operation, as previously described, is performed. The wound is then left wide open and is packed with dry gauze for two or three days. At the end of this time the gauze is removed, the edges of the wound are cleaned and the wound is covered with a cage made of wire netting which rests on a sterile rubber mat ¼ inch (0.6 cm.) thick and which has a window cut in it the exact size of the wound. This mat is sealed to the skin around the wound with collodion. The maggots, suspended in physiologic salt solution, are poured into the wound and the mat is covered with the wire netting cage and strapped down with adhesive tape. It is important that the mat be applied close to the skin and that the wire or screen be strapped close to the mat in order to prevent the maggots from escaping from the wound. The wound is then placed under an electric baker which is equipped with electric bulbs. As the maggots are averse to light, they will thus remain in the depths of the wound where they are supposed to do their best work. The larvae survive for from three to five days, at the end of which time the dressings are removed and the wound is thoroughly washed out with physiologic salt solution. Then a new supply of young maggots is placed in the wound.

As a rule, seven to ten applications of maggots are required before the wound is healed to a point at which their use is no longer necessary. I have not used this method, since it is my opinion that if an adequate operation be performed the application of maggots is not necessary and, if an adequate operation is not performed, I do

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been true in the past. By the judicious use of sulfathiazole, which is active against both staphylococcic and streptococcic infections, Dickson and Diveley recently have reported a series of twenty-one cases in which they operated in an attempt to cure chronic osteomyelitis and in which wounds were sutured. In all but two of these cases, healing occurred by primary intention. Their paper was read at the meeting of the Academy of Orthopedic Surgery in New Orleans in 1941, and has not yet been published. The method is as follows:

Two or three days prior to the operation the patient is given full doses, depending on his weight, of sulfathiazole or sulfadiazine by mouth. At the time of the operation the skin is prepared as though a clean operation were to be performed. Methylene blue is then injected into the sinus in order that all of the exposed, infected tissue is stained and thus may be easily recognized. The operation is performed with a tourniquet in place, if it is possible to apply one. The sinus is completely excised, the bone is rather widely exposed, all of the infected granulation tissue is excised, and a complete saucerization operation is performed, sequestra and all dead bone being removed, if possible. The infected scar tissue is excised rather generously. Hemostasis is then secured and the wound is sprinkled lightly with sulfathiazole powder (Dickson and Diveley use an atomizer) and the wound is sutured with catgut and immobilized in a plaster-of-paris cast.

I have used this method in seventeen cases with success. The oral administration of sulfathiazole is continued for a few days after the primary suture. If it is to be successful the operation must be well done and little or no infected bone or granulation tissue should be left exposed in the wound. When the operation can be successfully done, it greatly lessens the period of convalescence and permits the wound to heal.

not believe that application of maggots will result in healing. Also, it is necessary that the maggots be kept sterile. This is expensive as the maggots must be secured fresh at the proper time and of the proper age. Consequently, elaborate equipment is necessary if one is to raise one's own supply of maggots. As a result of the difficulty in securing the sterile maggots, and probably because of the disgusting aspects of the treatment, this method is relatively little used at this time.

Allantoin Treatment; Urea Treatment

Since the extracts of maggots were found to contain allantoin, and since this was believed to be the active principle which stimulated the granulating tissue in wounds that were subjected to the maggot treatment, certain investigators have used gauze saturated with a 2 per cent, or stronger, solution of allantoin.

Other investigators have used a solution of urea which relatively closely resembles allantoin chemically, in an attempt to increase the rapidity of healing of wounds after radical operations for the cure of osteomyelitis. I have had no experience with either of these substances and it is very difficult to judge the efficacy of a given material in hastening the healing of a chronic wound. However, they may be tried by those who desire to do so.

Carrel-Dakin Method

This method was widely used during the war of 1914–1918 and still has some adherents. The saucerization operation is performed, as has been described previously, and soft rubber tubes, with one end tied and perforations in the sides near this end, are laid in such a manner that they reach the recesses of the wound. The margins of the wound are then covered with vaseline gauze and the wound is packed with dry gauze and covered with a massive, dry dressing which is so applied that the open ends of the tubes project from the dressing.

Dakin's solution is injected into these tubes every two hours, day and night, and the wound is dressed daily. The use of Dakin's solution is not started until forty-eight hours after the operation on account of the danger of hemorrhage, and the first dressing is done on the third day. The method is laborious and painful and I do not believe that it is as effective as the Orr method.

Primary Suture after Operation

With use of the sulfonamide drugs, it has been possible to employ surgical treatment in the presence of infection much more than has

CHAPTER XXI

SPECIAL OPERATIONS FOR OSTEOMYELITIS

Humerus

The humerus is best approached from the outer side. In the upper portion the incision should lie along the anterior portion of the deltoid muscle. If necessary, the anterior portion of the deltoid may be removed from its insertions and reflected outward. In the lower portion the incision lies along the anterior border of the triceps muscle, between this and the biceps and, as the forearm is approached, the incision continues anterior to the intermuscular septum, lying anterior to the radial nerve after it pierces the septum. The entire length of the shaft, if necessary, can be exposed.

Ulna

The ulna can be exposed along its entire length, or as far as necessary, by an incision along its subcutaneous border.

Radius

In its upper portion the radius is best exposed by a posterior incision which lies along the anterior border of the anconeus muscle and extends toward the ulna in order that the posterior interosseous nerve, which lies in the substance of the supinator brevis muscle, may not be injured. In the lower portion, the radius is exposed by an incision which lies anterior to the brachioradialis muscle. The incision is carried directly down to the bone.

Femur

The upper portion of the femur is best exposed by a lateral incision, which begins at the trochanter and extends directly downward. The fascia lata is divided or split and the muscles overlying the bone are divided and reflected. The middle and lower portions of the femur are exposed by a posterolateral incision. Probably the operation most frequently performed in an attempt to cure chronic osteomyelitis is that on the lower end of the femur. Not only is involvement in this region of very frequent occurrence, but it is an

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extremely difficult region from which to eradicate the disease. It will be found that the disease is, as a rule, chiefly in the posterior portion of the bone, that is, adjacent to the popliteal space, and that it extends entirely across the bone. Consequently, the bone is approached from the lateral aspect, even though there may be a large central cavity, with sinuses, on the mesial aspect. Occasionally, both lateral and mesial incisions are used. Then the posterior and lateral portion of the bone is removed, exposing the central cavity. As a rule, this can be extended directly through the bone, thus saucerizing the bone from the posterior aspect, care being taken not to enter the joint. The anterior portion of the cortex is left to provide the integrity of the bone.

Tibia

The tibia usually is approached along its mesial, or subcutaneous, aspect. Since it, like the femur, tends to be more severely infected in its posterior part, this incision is best made parallel to the posterior border of the tibia rather than along its crest. The incision should be long enough to expose a sufficient length of the bone so that the cavity can be saucerized.

Metacarpal and Metatarsal Bones

These bones are best exposed on the dorsum of the hand or foot. If possible, exposure should be obtained without undue damage to tendons and with as little direct exposure of tendons as possible. A relatively large proportion of these small bones can be removed or subperiosteal resection can be performed if it is deemed necessary.

Fibula

The fibula is exposed by a lateral incision lying posterior to the peroneal muscles and following the intermuscular septum down to the bone, care being taken not to injure the peroneal nerve as it winds forward and downward around the neck of the fibula just below its head. In cases of extensive infection of the fibula it is wise to remove the bone over a portion of its shaft commensurate in length with the extent of the infection, because removal of the bone does not seriously interfere with function of the leg. To remove the bone it is exposed as has been described, and is cut in its lower portion with a Gigli saw or with heavy, bone-cutting forceps in order not to crack it downward and thus possibly to extend the infection into the part that is left. The shaft is then grasped and pulled outward, is dissected from the underlying soft tissue and periosteum, and is severed

close to its head, care being taken not to cut the peroneal nerve. The wound is then packed open, or it may be almost entirely sutured but left open at the ends and drained with a small wick of vaseline gauze. The fibula of a young child can be expected to regenerate. The fibula of an older child or adult probably will not regenerate entirely. Whether or not the fibula regenerates, if the external malleolus and a small portion of the shaft are left, there probably will be no disability as a result of removal.

Subperiosteal Resection

This operation has been practiced off and on for years and has some adherents. Except for using it in operating on the fibula, ribs and the metatarsal and metacarpal bones, I have performed it in only one case and, as I have stated previously, in that case the leg was later amputated. The patient was an adult. If it is performed on a young child at the proper time, usually from fifteen to eighteen days after onset of the acute infection, probably regeneration will occur. If the surgeon waits until an involucrum has become well formed and then resects the bone, probably regeneration will not occur. I do not see any reason for performing this operation early on young children, because I believe that the bone can be adequately drained and, especially in the case of young children, the disease usually can be cured without resection. In cases of osteomyelitis of the ribs, wherein it makes little or no difference whether the rib regenerates, resection always should be done if the disease is chronic. Likewise, occasionally in operating on small bones such as the metacarpals or metatarsals, exclusive of the first metacarpal or first metatarsal, the shaft can be resected with relative impunity.

I do not recommend the operation on any bone which cannot be dispensed with, as the danger of failure of regeneration outweighs any benefit which is likely to be gained by the operation.

Tarsal and Carpal Bones

Osteomyelitis of the tarsal bones, with the exception of the calcaneus, and osteomyelitis of the carpal bones occasionally indicate complete removal of the infected bone. This can be done with relatively little difficulty.

The Calcaneus.—Chronic osteomyelitis, or acute or subacute osteomyelitis, of the calcaneus is, I believe, best treated by the heel-splitting operation of Gaenslen. The patient is placed on his face after he has become anesthetized. A vertical incision is made, beginning 1 or 2 inches (2.5 or 5 cm.) above the tuberosity of the calcaneus; the inci-

sion extends directly through the tendo achillis and downward to the calcaneus, splitting the sole of the heel in the middle. Then, without reflecting the tissues outward, an osteotome is driven into the tuberosity of the calcaneus, splitting it in two. As it is pried apart the bone is split in two pieces. If the infection extends into the talocalcaneal joint, the incision is continued downward and outward to the anterior portion of the body of the calcaneus and the entire bone is split, thus opening both the talocalcaneal and the calcaneocuboid joints. Frankly necrotic material which is present in the interior of the bone is removed, the wound is sprinkled with crystals of sulfanilamide or sulfathiazole, packed open with vaseline gauze, and the extremity is immobilized in a plaster-of-paris cast. Unless there is considerable infection outside the cortex of the bone, the wound usually will heal relatively promptly and there will be left a narrow, deep scar which retracts and on which the patient can walk with little or no disability. If the talocalcaneal and calcaneocuboid joints have been opened, it can be expected that these joints will undergo fusion, but there will be little or no disability as a result of the fusion.

Ilium

Badgley has shown that almost the entire ilium can be removed without marked disability in case of chronic osteomyelitis. The incision starts posteriorly, at the posterior superior spine or slightly below it, and extends forward along the crest of the ilium, the incision in the skin lying about ½ inch (1.25 cm.) below the crest. It extends to the anterior superior spine and is then carried downward between the tensor fasciae femoris and the sartorius muscles. The fascia is cut about ½ inch (1.25 cm.) below the crest of the ilium and the gluteal muscles are then stripped subperiosteally. As the muscles are stripped, the wound is packed tightly with dry gauze to control the loss of blood which is, as a rule, not great. Having exposed the lateral surface of the ilium, the muscles are then stripped subperiosteally from the crest of the ilium, which is exposed on its inner surface. This also is exposed subperiosteally by stripping the muscles. Thus, the ilium, or most of it, lies projecting in a relatively large wound, the incision on the outer side being carried down to the superior border of the acetabulum.

In the two cases in which I have performed this operation, the ilium was greatly thickened. My recollection is that in places it was at least 2 inches (5 cm.) thick, although this may be an exaggeration.

A large, thin osteotome is then used and driven directly backward through the bone near the depth of the wound, and as much of the

bone as is infected is excised. If necessary, the incision may be carried back to the sacro-iliac joint. If, after removal of the large mass of bone, it is found that the remaining bone is infected, some of it may be removed. However, removal must not be carried down to include complete section of the pelvis; the bone over the sacrosciatic notches must be left intact. The wound is then sprinkled with sulfathiazole powder and closed, the anterior portion being packed with



Fig. 75.—Appearance of ilium after extensive resection for chronic osteomyelitis (Key in Lewis: Practice of Surgery. W. F. Prior Co, Inc.).

vaseline gauze. As a rule, there is not a great deal of bleeding (Figs. 75, 76, 77).

In the two cases in which I have performed this extensive operation healing has occurred and has persisted for three and five years respectively, which were the limits of the follow-up.

If the infection is in smaller portions of the ilium, and is fairly well localized, the diseased bone can be reached and excised with relative ease and, as a rule, the wound will remain healed. In spite of the large amount of bone removed in resection of the ilium, there

sion extends directly through the tendo achillis and downward to the calcaneus, splitting the sole of the heel in the middle. Then, without reflecting the tissues outward, an osteotome is driven into the tuberosity of the calcaneus, splitting it in two. As it is pried apart the bone is split in two pieces. If the infection extends into the talocalcaneal joint, the incision is continued downward and outward to the anterior portion of the body of the calcaneus and the entire bone is split, thus opening both the talocalcaneal and the calcaneocuboid joints. Frankly necrotic material which is present in the interior of the bone is removed, the wound is sprinkled with crystals of sulfanilamide or sulfathiazole, packed open with vaseline gauze, and the extremity is immobilized in a plaster-of-paris cast. Unless there is considerable infection outside the cortex of the bone, the wound usually will heal relatively promptly and there will be left a narrow, deep scar which retracts and on which the patient can walk with little or no disability. If the talocalcaneal and calcaneocuboid joints have been opened, it can be expected that these joints will undergo fusion, but there will be little or no disability as a result of the fusion.

Ilium

Badgley has shown that almost the entire ilium can be removed without marked disability in case of chronic osteomyelitis. The incision starts posteriorly, at the posterior superior spine or slightly below it, and extends forward along the crest of the ilium, the incision in the skin lying about ½ inch (1.25 cm.) below the crest. It extends to the anterior superior spine and is then carried downward between the tensor fasciae femoris and the sartorius muscles. The fascia is cut about ½ inch (1.25 cm.) below the crest of the ilium and the gluteal muscles are then stripped subperiosteally. As the muscles are stripped, the wound is packed tightly with dry gauze to control the loss of blood which is, as a rule, not great. Having exposed the lateral surface of the ilium, the muscles are then stripped subperiosteally from the crest of the ilium, which is exposed on its inner surface. This also is exposed subperiosteally by stripping the muscles. Thus, the ilium, or most of it, lies projecting in a relatively large wound, the incision on the outer side being carried down to the superior border of the acetabulum.

In the two cases in which I have performed this operation, the ilium was greatly thickened. My recollection is that in places it was at least 2 inches (5 cm.) thick, although this may be an exaggeration.

A large, thin osteotome is then used and driven directly backward through the bone near the depth of the wound, and as much of the

Chronically Infected Compound Fractures with Nonunion

These present a serious problem and require at least two, and sometimes three, operations for cure (Figs. 78, 79). The first operation is radical excision of the infected tissue, in which all loose pieces of bone and bone which is obviously dead are removed; there is no serious objection to sacrifice of some length. The wound is then packed open with vaseline gauze, as was described previously for the treatment of chronic osteomyelitis, and sulfanilamide or sulfathiazole

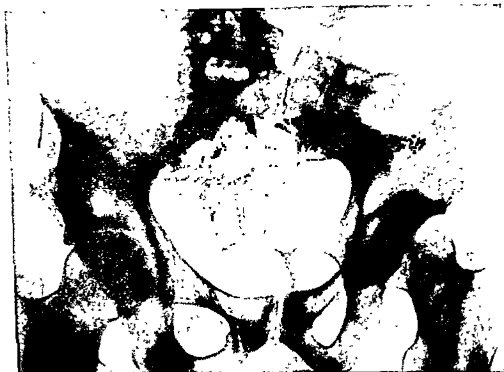


Fig. 77.—Chronic osteomyelitis of the sacro-iliac joint. Lesion was similar to that represented in Fig 75. In spite of extensive resection there is still some evidence of infection in the thickened ilium (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

is used generously in the wound. During the past year most of these wounds have been closed after the radical operation according to the method of Dickson and Diveley as previously outlined. In other instances it is necessary that the wound be permitted to heal by granulation from the bottom up. After the wound has healed, the wide scar is excised, as is the scar tissue between the bones. The wound is sprinkled generously with sulfanilamide or sulfathiazole, and closed. After this has healed and has remained healed for a few months, a bone-grafting operation is performed through an incision in healthy

appears to be no difficulty as a result of the operation, although in my experience complete regeneration by no means has occurred.

Amputation

Amputation is occasionally justified for the cure of osteomyelitis in a case of long-standing infection in which cure by other operative means is impossible. However, most patients prefer a leg with a sinus to an artificial leg. In two cases of osteomyelitis in which I have performed amputation, the tibia had been resected and had failed to



Fig 76—Appearance of wound four years after extensive resection of the ilium for chronic osteomyelitis. There was no evidence of infection when this picture was made (Key in Lewis: Practice of Surgery. W. F. Prior Co., Inc.).

regenerate. In both cases the patients were adults and both preferred amputation rather than an attempt to use the fibula as a graft with the hope that it would strengthen the tibia sufficiently to permit weight bearing. In one instance the amputation was performed just above the condyles of the femur and in the other the proximal portion of the fibula was transplanted into the short stump of the tibia and the leg was amputated at the point of election. In both cases a satisfactory result was obtained. In amputating for osteomyelitis it is important that the bone be cut above the site of the disease.

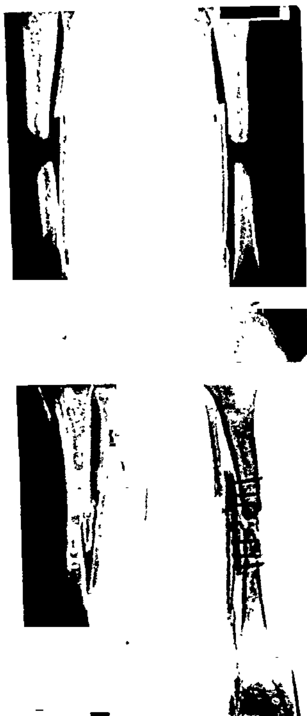


Fig. 79.—Roentgenograms made in same case as that represented in Fig. 78, but after operation and primary suture to eliminate infection; followed by a bone-grafting operation.



Fig. 78.—*Above*, compound comminuted fracture of the leg; *below*, roentgenogram made after the development of infection.



Fig. 79.—Roentgenograms made in same case as that represented in Fig. 78, but after operation and primary suture to eliminate infection; followed by a bone-grafting operation.

tissue; this will permit placing the graft beneath muscles, where it will have an ample blood supply. The space between the fragments is packed with bone chips and the graft is fixed firmly to the fragments with stainless steel screws. In my experience this usually will result in union as well as in cure of the infection. Before closure, the wound again is sprinkled with sulfathiazole powder.

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